Table B.6-2. Artificial Penetrations: MDEQ Oil and Gas Permits Penetrating the Confining Zone within Area of Review

API #	Well Location			Total Depth (ft. BGL) and formation at depth	Date of Completion or P&A	Permit Data	Casing and Plugging Information	
	Twn	Rng	Sec				Casing	Plug
21163058300000	4S	8E	22	2,564 ft; approximately 74 feet into the Trenton	Drilled in June 1940 as Trenton producer; P/A 12/24/42	P/A: Oil and gas Production well; plugged and abandoned two years after drilling.	22' – 10" (Pulled) 533' – 8 ¼" (Pulled) 1,333' – 6 5/8" (Pulled) 1,824' – 5 3/16" (Pulled)	Filled 300 pails of mud to bottom of 5 3/16". Pulled 5 3/16" and filled with mud – 283 pails – to 1,333'. Pulled 6 5/8" and filled with mud- 358 pails- to 200'. Filled with mud to bottom of 10". Pulled the 10" and filled with mud to surface.
21163194840000	4S	8E	27	2,761 ft; approximately 315 feet into the Trenton	Drilled Sept 15, 1955; P/A 10/10/1955	P/A: Oil and gas exploratory well, dry hole.	155" – 10" 1,740" – 8 ¼" (Pulled) 2,565" – 7" (Pulled) 2,714" – 5 ½" (Pulled 1,980' to surface)	Plugged back from TD to 2,570' with gravel and lead wood, heavy mud up into 5" casing. 5 1/2" ripped at 1,980' and mudded as it was pulled. 7" casing was started and mudded as it was pulled 8 1/4" casing started and mudded as it was pulled A bridge was set at 200' and hole filled with heavy mud to 10". 10" drive abandoned with hole, a cement plug set in top of 10"
21163037010000	4S	8E	27	2,566 ft; approximately 126 feet into the Trenton	Drilled June 15, 1937; plugged June 23, 1927	P/A: Oil and gas exploratory well, dry hole.	126" – 10" (Pulled) 689" – 8 ¼" (Pulled) 1758' – 6 5/8"	Filled with heavy mud to 2,448' and dropped 6" iron ball - filled with 100 buckets of mud and dropped 7" iron ball at 1,758'. Then put in 200 buckets of mud and pulled 8 ¼" casing and dropped a 9" iron ball and filled with 200 buckets of mud. Bridged at 150' pulled 10" casing and filled to surface and covered for safety.
21163192140000	4S	8E	26	2,827 ft; approximately 402 feet into the Trenton	Drilled January 10, 1955; Plugging completed January 26, 1955	P/A: Oil and gas exploratory well, dry hole	70' – 10" 625' – 8 5/8" (Pulled) 1728 – 7" (Pulled)	Mudded, TD to base of the 7" casing, started 7" casing at 1,294' and mudded as it was pulled to the base of 8" casing. Started 8" and set bridge at casing seat and mudded as it was pulled to the base of 10". 10" would not pull so mudded on to top of surface allowing for settling and put in cement bridge at plow depth in top 10' of drive pipe.
21163620000000	T4S	R8E	30	Total depth (measured depth for directional well) 3,100 ft;	Drilled 1/23/2018	P/A: Oil and gas exploratory well, dry hole	16" - 40' 11 3/4" - 246' 8 5/8' - 1,050' All casing left in place	Plug #1, 2,970' – 2,570', 120 sx Class "A" Plug #2, 1,530' – 1,330', 60 sx Class "A" Plug #3, 1,150' – 920', 100 sx Class "A" Plug #4, 400' – 150', 80 sx Class "A" Plug #5, 60' – Surface, 20sx Class "A"

Notes:
P&A = dry hole, plugged
O&G = Oil/Gas Well

Based on local data, four wells in the AOR are completed to vertical depths of 2,564 ft, 2,566 ft, 2,761 ft, and 2,827 ft, with Permit 61290 (API 21163620000000) completed to a measured depth of 3,100 ft (total vertical depth estimated to be 2,920 ft). These depths indicate that the bottomhole of each well was in the Trenton Formation or just through the Trenton into the top of the Black River. Based on regional Trenton/Black River interval thicknesses, approximately 300 feet of vertical separation exists between the bottom of the deepest penetrating well and the base of the confining zone. Since the CFL wells are proposed to be permitted for injection into the Franconia/Dresbach, Eau Claire, and Mt. Simon Formations below a depth of approximately 3,250 feet, approximately 400 feet of vertical separation exists between these shallower plugged and abandoned oil wells and the top of the injection interval.

Water Wells Within 2,000 Foot AOR

As shown on Figure A.4-6a and discussed in Section A.4, there are two water wells within 600 feet of the proposed IW#1-36N well location, and eleven water wells within approximately 2,000 feet of the CFL property boundary. Table B.6-3 summarizes the information for the wells identified within 2,000 feet of the CFL property boundary. Figure A.4-6b shows there are monitoring wells and piezometers in the area, most of which surround the eastern and southern boundaries of the CFL. Data for water wells are included in Attachment C (CD-ROM). Note that fresh water penetrations within a 2,000 foot radius of the CFL property boundary are typically no deeper than 135 feet BGL and, as such, are not critical with regard to the safety of fluid injection at the CFL site because none come close to penetrating the injection or confining zones.

Figure A.4-6b shows the location of monitoring wells associated with the Carleton Farms Landfill. These wells are shallow completions through the Alluvium and Glacial drift and are typically completed in carbonate bedrock, i.e., the Lucas Formation of the Detroit River Group.

Table B.6-3. Water Wells Within 2,000 Feet, Carleton Farms Landfill

Permit Number	County	T/R	Section	Date	Depth (ft)	Type	Bottom lithology	Well owner
81142990002000	Wayne	04S 08E	36	1975	67	Domestic	Limestone	John Stepzinski
580600100330	Monroe	05S 08E	1	1978	39	Domestic	Limestone Hard	Ron Rireur
580600101000	Monroe	05S 08E	1	1986	67	Domestic	Limestone	No data
580100600700	Wayne	05S 09E	6	1966	20	Not specified	Clay	No data
580600100700	Monroe	05S 08E	1	1973	50	Domestic	Limestone Hard	Fred Brown
No data	Wayne	04S 08E	25	1974	82	Domestic	Limestone Hard	David E Meyers
No data	Wayne	04S 08E	25	1971	67	Domestic	Limestone	Robert C Hamlet
No data	Monroe	05S 08E	2	1968	21	Domestic	Clay	Charles Trout
No data	Monroe	05S 08E	1	1995	51	Domestic	Limestone	David Slitti
No data	Monroe	05S 09E	6	1970	20	Domestic	Blue Clay	Sidney Manor

Corrective Action

As shown in Table B.6-2, there are five wells within the two mile AOR that penetrate into the upper portions of the confining zone, but do not fully penetrate into the injection zone or into the deeper injection interval. Well construction and abandonment information for these wells are included at the end of this Section (B.6).

As shown in Tables B.4-1 and B.6-2, and discussed above, no well fully penetrates the confining zone in the AOR. Therefore, the only wells that could potentially require corrective action would be the proposed IW#1-36N or IW#2-36E wells themselves. The following summarizes the plan to address failure of the inejctors to protect the surface environment and prevent migration of injected fluids into any USDW:

IW#1-36N and IW#2-36E Contingency Plan

Continuous monitoring and periodic routine testing will be performed on the disposal wells as required by applicable laws, permits and regulations, with Part II MIT occurriung not less frequently than once every five years as discussed in Section A.11 and A.14 of this document. Pertinent data will be forwarded to the agencies as required. This monitoring and testing is required to ensure well integrity and safe operations.

1. If a well fails required monitoring or periodic testing standards, the well will be shut-in and the agency notified according to applicable regulations and permit conditions. After investigation into the cause for the failure, work plans will be prepared and reviewed with the regulators for repairing the problem.
2. If a workover is performed on the well, copies of all work reports and logs will be forwarded to the regulatory agencies within 45 days.
3. During the period of time required for a well workover or for shut-ins due to MIT failure, the contingency plans of the facility will include the following:
   a. If shut-in period is sufficiently brief, the fluid generated during this period of time will be held in storage at the facility.
   b. If well shut-in is required for a longer period of time, some of the fluid may be shifted to another facility.
   c. If required, fluids will be removed from the facility via licensed waste transport vehicles and managed according to applicable regulations.

Although the well design and construction of well IW#1-36N and IW#2-36E and, as necessary, implementation of a Corrective Action Plan, would preclude the potential for endangerment of the USDW, further documentation is provided here as a calculation of the rise pressure in this reservoir that might have the potential to cause upward flow in a hypothetical pathway. The cone-of-influence (COI) for injection is defined as that area around a well within which increased injection zone pressures caused by injection could be sufficient to drive fluids into an underground source of drinking water (USDW). The pathway for this theoretical fluid movement is assumed to be a hypothetical, open abandoned well which penetrates the confining zone for injection. Information used in the following calculations has been estimated from logs and available neighboring well information summarized in this document.

Critical Pressure Rise

To calculate the COI, a value must first be assigned for the pressure increase in the injection interval that would be sufficient to cause injection zone brine to rise in an open pathway to the base of the lowermost USDW. This critical pressure rise, Pc, is assigned as indicated in Figure B.6-2 provided below.

The pressure required at the top of the injection interval to support injection zone brine in the configuration indicated is, in psi units:

$$P = 0.433\ [y_B D_B + y_w(D_w - L)]$$

where: $D_B = D_x - D_w$

and the pressure rise is then:

$$Pc = 0.433\ [y_B D_B + y_w(D_w - L)] - Po$$

where Po is the original, pre-injection value for pressure at the top of the injection interval expressed in psi units.

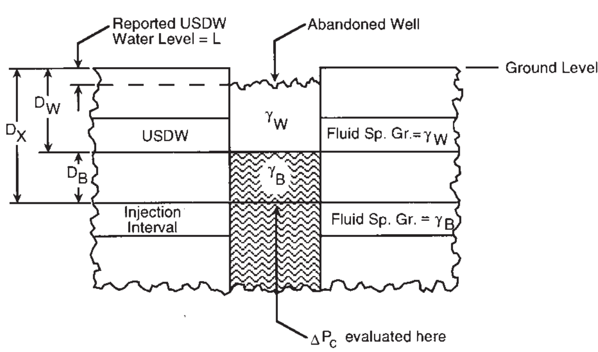

Figure B.6-2. Critical Pressure Rise

At the top of the Franconia through Mt. Simon injection interval at 3,281 feet below ground level (BGL), original pressure is estimated to be 1,516 psig (Table B.6-4). This estimate of original reservoir pressure is based on the measured pressure gradient in the EDS Class I wells located approximately 11 miles northeast of CFL. Based on data from the EDS Wells #1-12 and #2-12, as presented in the No Migration Variance

Petition (Subsurface, 2000). The original measured pressure at the EDS #1-12 well was 1,825 psi at 4,000 ft RKB (reservoir pressure gradient of 0.4577 psi/ft); the extrapolated pressure at well #2-12 at 4,265 ft RKB was 1983.5 psi (0.4665 psi/ft). Averaging these two values results in a reservoir pressure gradient of 0.462 psi/ft, which is utilized for reservoir characterization of the injection interval at the CFL site in this document. This value is consistent with regional data for the Mt. Simon in this portion of Michigan.

Original pressure of the top of the injection interval at the IW#1-36N well is calculated as 3,281 ft * 0.462 psi/ft = 1,516 psig. A specific gravity of 1.20 is assigned to the injection interval brine based on the TDS value of 270,000 mg/L reported from the EDS well #2-12 (see Section B.8, Table B.8-5). This value of specific gravity was calculated from the CREWES Fluid Properties Calculator (Crewes, 2019), based on a temperature of 89 degrees Fahrenheit at the midpoint of the injection interval and a salinity concentration of 270,000 mg/L. The temperature at the midpoint depth (i.e., midpoint between the top of the injection interval and total depth) is based on the reported bottomhole temperature (BHT) from the EDS well #1-20 well log, which reported a maximum BHT of 100 degrees Fahrenheit. This is equivalent to a geothermal gradient of approximately 1.2 degrees per 100 feet (assuming mean annual temperature at the surface of 47 degrees Fahrenheit). At an estimated midpoint depth of 3,554 feet (IW#1-36N) and 3,537 feet (IW#2-36E) and utilizing a gradient of 1.2 degrees/100 feet results in an estimated temperature of approximately 89 degrees. This value of temperature is utilized to evaluate the expected specific gravity and viscosity that are utilized in the following calculations. Note that this geothermal gradient value is lower than the regional gradient of of 1.4 degrees/100 feet shown on the geothermal gradient map of Michigan provided by Vaught (1980).

In assigning the critical pressure rise and calculating the cone-of-influence at this site, the base of the lowermost USDW is assigned as 400 feet BGL, which corresponds to the top of the Bass Islands at IW#1-36N. No water level data is available in this unit, as there are no regional wells which are completed to this formation. Shallower groundwater levels range between approximately 10 to 15 feet below ground level. Therefore, a depth to water in the lowermost USDW is conservatively estimated at 30 feet.

Table B.6-4. Critical Pressure Calculation Parameters

Parameter	Value
Original pressure of injection interval, Po	1,516 psi @ 3,281 feet
Depth to base of USDW, D_w	400 feet
Depth to top of injection interval, D_X	3,281 feet
Depth to USDW fluid level, L	30 feet
Density (specific gravity) of USDW fluids, y_w	1.0
Density (specific gravity) injection zone brine, y_B	1.20

These values were used in the above equation to compute the critical pressure rise (Pc) as follows:

$$Pc = 0.433[1.20(3{,}281 - 400) + 1.0(400 - 30)] – 1{,}516 \text{ psi}$$
$$Pc = 141 \text{ psi}$$

Note that the Pc calculation is based on estimated depths at IW#1-36N; the calculated Pc value at IW#2-36E is approximately 142 psi. Therefore, the lower Pc value is utilized for cone-of-influence calculations presented below.

Cone-of-Influence

Based on the critical pressure rise, the cone-of-influence (COI) can be calculated for the IW#1-36N and IW#2-36E wells. The COI is calculated based on a maximum proposed injection rate of 80 gpm per well for 20 years (160 gpm combined injection). The pressure rise due to injection is calculated at each well, and the results of these calculations are summed together to provide an estimation of the total pressure rise due to injection from the two-well system.

Pressure rise due to injection can be evaluated by an examination of the following estimate (oilfield units) of pressure rise (Lee, 1984) in the reservoir at each disposal well:

$$dP = -70.6\, Bq\mu / kh * \ln ([1{,}688\, \phi\, \mu c_t r^2 / kt] – 2s)$$

Values utilized in the above calculation are listed in Table B.6-4 and have been assigned based on data from the EDS Class I wells in Romulus, MI, located approximately 11 miles northeast of the CFL facility. Additional details of testing data at these wells is provided in Section B.8.2.2.2. The net thickness of the injection interval is conservatively assigned a value of 210 feet, and the permeability is conservatively assigned as 110 millidarcies (md). Based on an estimated temperature of 89 degrees at the midpoint of the injection interval, and a TDS value of 270,000 mg/L, a viscosity value of 1.55 centipoise (cP) was calculated from the CREWES Fluid Properties Calculator (Crewes, 2019), as shown in Table B.6-5.

Pressure rise due to injection according to the previous equation by Lee (1984) was evaluated at each proposed well, based on the maximum injection rate of 80 gpm per well, and this one-dimensional solution was applied radially with respect to each well to characterize a two-dimensional evaluation of pressure rise. The results of these pressure rise calculations at each well were added together utilizing the Surfer gridding and contouring software program (Golden Software, 2019).

Table B.6-5. Cone of Influence Parameters

Parameter	Calculation	Value
Flow rate, q	80 gpm *1440 min/day* bbl/42 gal	2,743 bbl/d
Thickness, h	Portion of the ~550 foot thickness of the injection interval	210 feet
Formation Volume Factor, B	Correlation	0.997
Porosity, ϕ	Logs	0.11
Permeability, k	Well tests	110 millidarcies
Viscosity, μ	Correlation	1.55 centipoise @ 89 degrees F
Total Compressibility, C_t	3.1×10^{-6} psi^{-1} + 4.5×10^{-6} psi^{-1}	7.6×10^{-6} psi^{-1}
Radius, r	Illustrative assumption	10,560 feet
Time, t	20 years x 365.25 days/yr * 24hr/day	175,320 hours

Figure B.6-3 presents the combined calculated pressure rise due to injection at each well for a 20-year duration. To evaluate the COI, the previously calculated value of critical pressure rise (Pc; 141 psi), which represents the pressure required to cause vertical migration through a hypothetical open borehole to the lowermost USDW, must be evaluated versus the calculated reservoir pressure rise from injection.

Based on the calculated pressure rise due to injection presented on Figure B.6-3, the calculated critical pressure rise (141 psi) extends to a distance of approximately 4,400 feet or more from the two proposed wells. At the two-mile AOR with respect to the CFL boundary, calculated pressure rise ranges from approximately 93 to 105 psi, which is significantly less than the calculated Pc value. In addition, the calculated radii of piston-like displacement (1,245 feet) of injected fluid for each of the two wells are also shown on Figure B.6-3, which is detailed in Section B.12. Note that the calculated critical pressure rise value of 141 psi does not extend to any of the five plugged and abandoned historical oil wells identified in the two-mile AOR, and the calculated pressure rise that corresponds to the calculated Pc value is more than 3,100 feet east of the nearest oil and gas well.

Therefore, the maximum cone-of-influence at this site is projected to be within a 2-mile radius around the wells and property boundary, even under a conservative scenario. Due to the relatively large permeability-thickness of the injection interval at this site, there exists no potential for contamination of USDW resources due to improperly completed or abandoned wells within the statutory minimum 2-mile radius AOR. The nearest wells that penetrate both the confining or injection zone are located approximately 7 to 11 miles to the northeast at the EDS facility in Romulus, MI, where there are two non-hazardous injection wells completed to the Franconia to Mt. Simon Formations.

A corrective action plan is not required for any of the artificial penetrations within the AOR because, based on calculations, there are no wells within the cone-of-influence and there are no artificial penetrations to the injection zone within the area of review that have the potential for allowing injection activities to have an impact on the USDW. If a corrective action plan for any neighboring well becomes necessary in the future, it will be developed according to appropriate regulatory requirements.

The corrective action plan which would be proposed by CFL, should fluid migration occur through the confining layer, will include the following:

1. Disposal well(s) will be shut-in.
2. The US EPA, Region 5 UIC Section and EGLE will be notified.
3. Following well shut-in, liquid waste will be shipped to alternative permitted facilities for off-site treatment and disposal as necessary.
4. A contingency plan will be prepared as follows:
   a. Locate well and identify present operator or owner, if any.
   b. Identify mode of failure.
   c. Prepare remedial plan outlining course of action.
   d. The remedial plan will be submitted to EGLE and US EPA, Region 5 for approval.
   e. Upon authorization, the remediation plan will be implemented.

Area of Review Oil and Gas Well Data

As discussed above and presented in Section B.4, there are five wells that penetrate the confining zone within the two-mile AOR, though none of these penetrate past the base of the confining zone or into the injection zone or injection interval. Figure B.4-1 shows the location of deep non-freshwater penetrations within the AOR and Table B.4-1 presents a summary of information for these wells located in the AOR. Table B.6-2 presents a summary of available information regarding the plugging of these wells.

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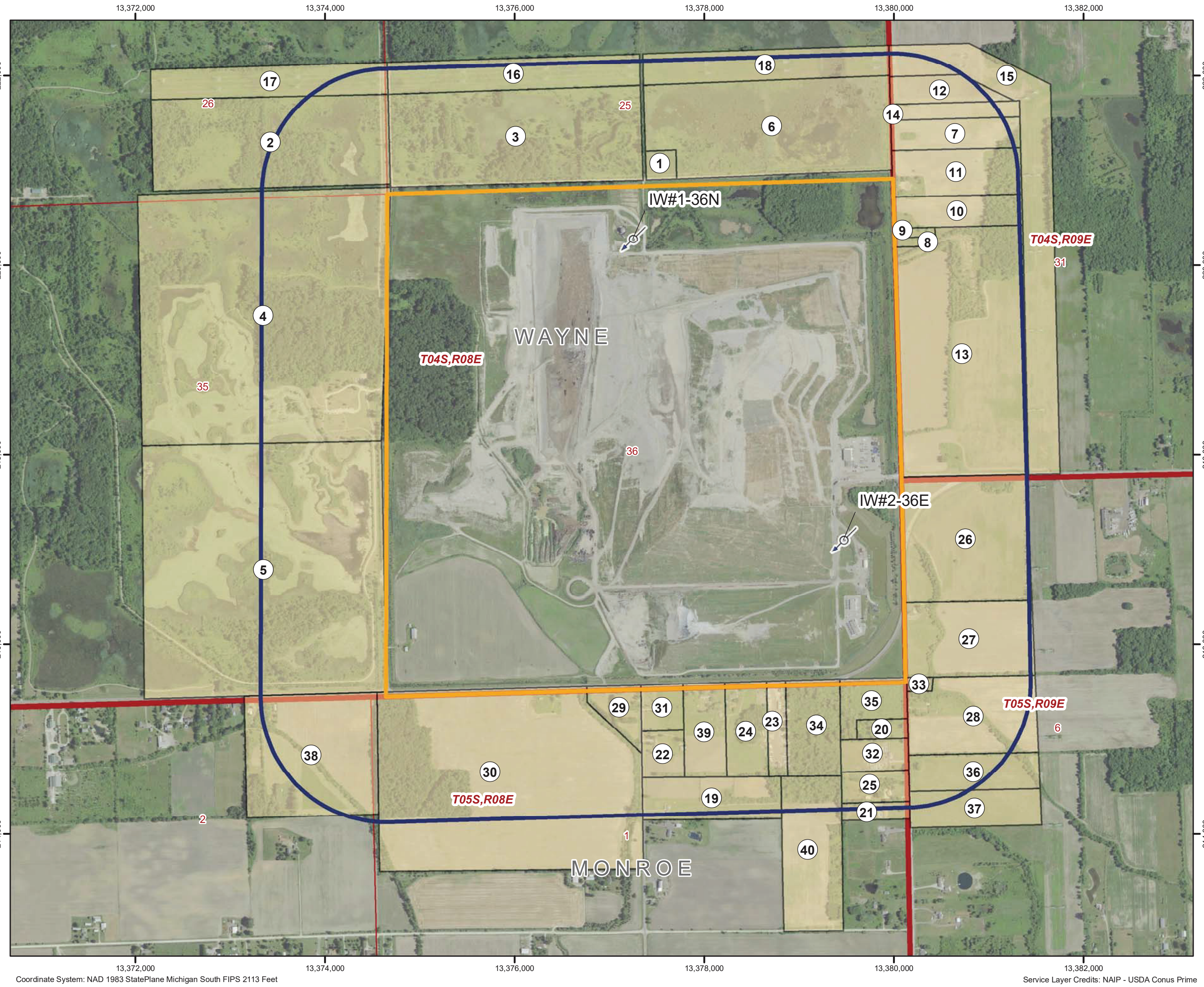

REPUBLIC SERVICES

Figure B.6-1
Property Parcels Adjacent to the Carleton Farms Landfill

2019 Permit Application

Scale: 1:12,000	Date: May 2020
2019_CFL_EGLE_Fig_B.6-01.mxd	By: WEK Checked: CW

Petrotek
5935 South Zang Street, Suite 200
Littleton, Colorado 80127 USA
303-290-9414
www.petrotek.com

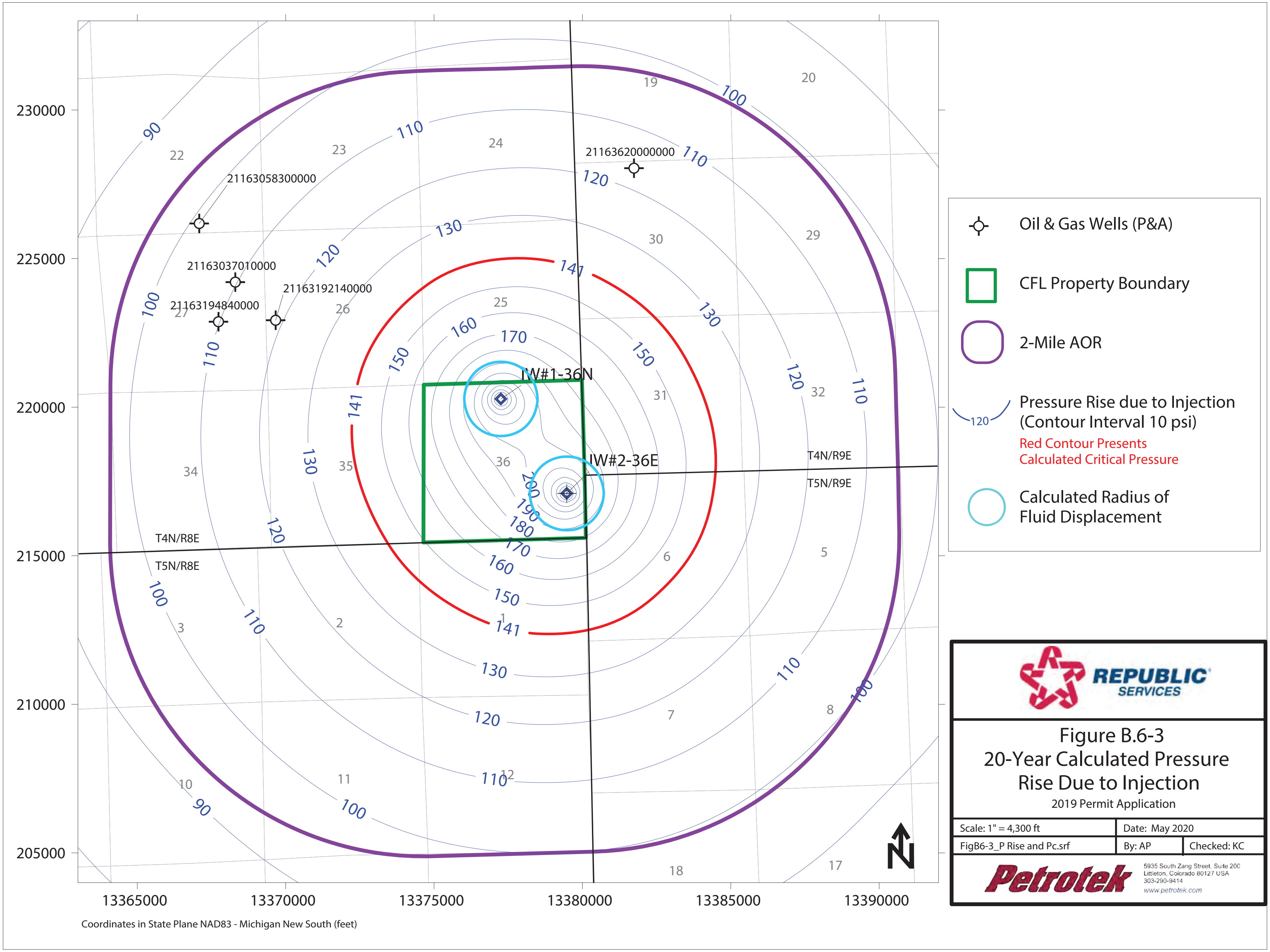

Figure B.6-3
20-Year Calculated Pressure Rise Due to Injection
2019 Permit Application

Scale: 1" = 4,300 ft	Date: May 2020	
FigB6-3_P Rise and Pc.srf	By: AP	Checked: KC

B.7 A map showing the vertical and areal extent of surface waters and subsurface aquifers containing water with less than 10,000-ppm total dissolved solids. A summary of the present and potential future use of the waters must accompany the map.

Figure A.4-4 (Section A.4) is a topographic map of CFL area, and shows there are mappable surface water features in the immediate vicinity of CFL, although survey has shown there are no such features within a 1,320 ft radius of the proposed well locations except for Mosquito Drain (see Attachment C, Environmental Assessment Report). See Section A.4 for additional discussion. Surface water is not a local drinking water source.

Figure B.7-1 (Section B.7) presents the Michigan Stratigraphic Column which shows both the name and age of rock units including those that may be subsurface aquifers. The Michigan Groundwater Atlas discusses aquifers present in Michigan (Olcott, 1992), and data from this source indicates that CFL is underlain by a surficial layer composed of glacial clay and intermittent sands, that is underlain by the regional Silurian-Devonian aquifer system.

Site specific data obtained during hydrogeologic studies supporting landfill permitting (City Management Corporation, 1991) identified shallow water-bearing intervals in the CFL area that are monitored as part of the landfill operating permit requirements. This study verified that glacial clay/sand occur above bedrock, and the Devonian Detroit River Group (i.e., Lucas Formation) is the bedrock unit that underlies the landfill area (Figure B.7-2). Bedrock is overlain by glacial clay, above which a discontinuous sand layer may be present. Thickness of surficial sand varies from 0-13 feet, and glacial clay varies from 80 feet thick near the northern boundary of Sumpter Township to less than 40 feet at the southern boundary; glacial sediments are approximately 53 feet thick at the IW#1-36N well location and 30 feet thick at the IW#2-36E well location. The 1991 hydrogeologic report also states that the primary groundwater aquifer occurs in the carbonate rock formation underlying glacial material, which is locally fractured and exhibits solution features at the bedrock surface. It is also noted that this report states that karst or zonation at the carbonate surface is expected to be minimal due to the "apparently uniform distribution of fractures in the upper portion of the rock formation". Figure B.7-3 and B.7-4 present local cross sections that show overlying glacial material above bedrock at the CFL area.

Bedrock aquifers are typically confined in the region. Groundwater flow in the uppermost bedrock carbonate aquifer is from northwest to southeast in Sumpter County (City Management Corporation, 1991), as verified by local potentiometric surface maps (Figure B.7-5). According to the Hydrogeologic Report, groundwater wells in the region range in depth form 17 to over 100 feet, with an average dept of 47 feet, and are typically drilled to the uppermost bedrock surface. Figure A.4-6a presents the location of water wells around the CFL area. Data used to construct this map verifies that most water wells are completed within the upper bedrock surface, i.e., the Lucas Member of the Detroit River Group, which subcrops immediately below the surficial glacial material.

The specific geologic unit that subcrops below overlying glacial material varies within Wayne and Moore Counties due to erosion, and the USGS (Apple and Reeves, 2007) states that the Bass Islands and Salina Group, where present immediately below glacial material, are the lowermost units within the Silurian-Devonian aquifer system that may be a source of drinking water at the bedrock-glacial material interface. However, both of these units are far below ground level at CFL, and are not used as underground sources of drinking water due to depth, water quality, occurrence of water in shallower intervals, and availability of public water supplies. It should be noted that karst solution features may be present in shallow carbonate units, significantly increasing local porosity and permeability. Further, as indicated by Nicholas et al. (1994), average well depths for bedrock wells in Monroe County are typically less than 200 feet, and generally corresponds to the top of the bedrock unit that underlies alluvium or glacial deposits, meaning that drinking water wells are typically completed in whatever formation that subcrops in the area, which can vary due to bedrock dip.

Groundwater Use and Water Quality

As indicated above, use of groundwater as a drinking water source in the CFL area is minimal, due to the availability of water supply through the Detroit Water and Sewer Department, and because groundwater quality in bedrock aquifers is poor and generally considered non-potable due to high mineralization and high sulfur content. Water quality data obtained as part of the original landfill construction permit application indicated the following average ion concentration in groundwater obtained from the fractured upper surface of the Detroit River Group carbonate (Lucas Formation) below glacial clay:

- 213.1 ppm Ca
- 101 ppm Mg
- 89 ppm HCO_3
- 1215 ppm SO_4
- 99 ppm sodium
- 196 ppm chloride

The USGS Groundwater Atlas (Olcot, accessed 2019) states that the regional Silurian-Devonian groundwater aquifer system includes the Detroit River Group, Sylvania Sandstone, Bois Blanc-Bass Islands in Wayne and Monroe counties, with underlying units of the lower Silurian serving as confining units. The Groundwater Atlas also indicates that the water quality specific to the Silurian-Devonian aquifer system becomes quite saline in the general vicinity of CFL, indicating that while the unit may be water bearing, the water quality can vary significantly with depth exceeding 100,000 mg/L TDS just east of the facility. Figure B.7-6 presents a general water quality portrayal of the Silurian-Devonian aquifer system, which indicates that the water quality below the CFL within this system may exceed the 10,000 mg/L TDS, particularly with depth. The Groundwater Atlas states “Downdip, at, or near the contract of overlying rocks, dissolved-solids concentrations increase to 1,000 milligrams per liter….A short distance farther downdip, the water is a brine; dissolved solids concentrations in excess of 160,000 milligrams per liter have been reported in water from these rocks in the center of the Michigan Basin”. As shown in the site-specific listing above, water quality within the uppermost bedrock aquifer immediately below glacial clay exhibits very high sulfate content as well as other dissolved solids, confirming regional assumptions.

Water quality calculations can be performed to assess the concentration of total dissolved solids, and to hence identify the base of the lowermost underground source of drinking water. These calculations were performed at the EDS #2-12 well (Subsurface, 2002), which is relatively close to the CFL; these calculations determined that the formation fluids below a depth of 387 feet RKB exhibited total dissolved solid concentrations in excess of 10,000 ppm. This depth corresponds to the base of the Sylvania Sandstone at the EDS #2-12 location, which occurs below a thick Detroit River Group at EDS #2-12. At CFL, the Detroit River Group (Lucas Formation) appears to be relatively thin, as the Sylvania Sandstone occurs at about 135 feet BGL in at least one location. Taking this into account and water quality calculations performed at the EDS wells, the base of the lowermost USDW is conservatively assigned to the unit below the Sylvania Sandstone, i.e., the Bois Blanc Formation, the base of which is estimated to be approximately 400 feet below ground level.

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STRATIGRAPHIC NOMENCLATURE FOR MICHIGAN

Michigan Dept. of Environmental Quality
Geological Survey Division
Harold Fitch, State Geologist
and
Michigan Basin Geological Society

Stratigraphic Nomenclature Project Committee:
Dr. Paul A. Catacosinos, Co-chairman
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This work is the product of the combined efforts of the geological communities of Michigan and the surrounding states and provinces. Below are given just a representative few of the contributors:

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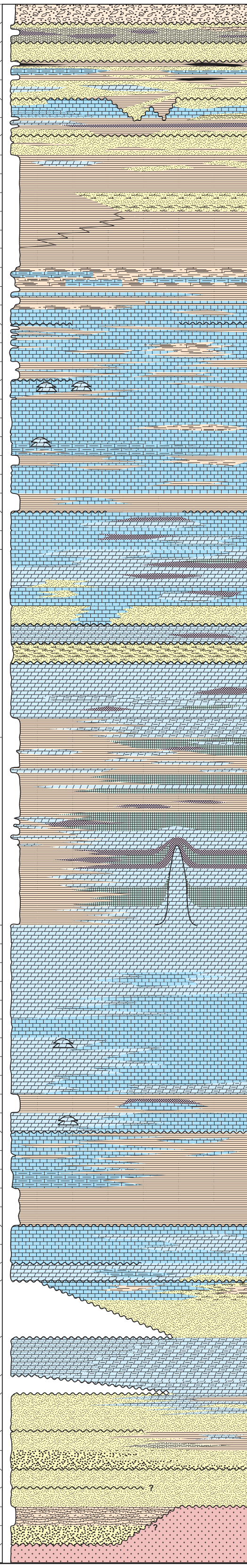
Government: Dr. Terry R. Carter, Ontario Ministry of Natural Resources; Mr. John M. Esch, Michigan Department of Environmental Quality; Dr. Brian D. Keith, Indiana Geological Survey; Mr. Lawrence H Wickstrom, Ohio Geological Survey.

Industry: Mr. Donald J. Bailey, Consultant; Mr. Jimmy R. Myles, Scot Energy; Mr. Dan E. Pfeiffer, Pfeiffer Exploration Services.

A complete listing of all contributors will be found in the Stratigraphic Lexicon for Michigan, of which this column is an integral part.

GEOLOGIC TIME / OUTCROP NOMENCLATURE / DOMINANT LITHOLOGY / SUBSURFACE NOMENCLATURE

ERA	PERIOD	EPOCH	NORTH AMERICAN STAGES	GROUP	FORMATION	MEMBER	FORMATION	GROUP
Cenozoic	Quaternary	Pleistocene	Wisconsinan		Glacial Drift		Glacial Drift	
Mesozoic	Jurassic	Middle	Oxfordian		Ionia Fm		Ionia Fm	
Paleozoic	Pennsylvanian	Late	Conemaugh		Grand River Fm		Grand River Fm	
		Early	Pottsville		Saginaw Fm		Saginaw Fm	
					?—?—? Parma Ss		?—?—? Parma Ss	
	Mississippian	Late	Meramecian		Bayport Ls		Bayport Ls	
					Michigan Fm		Michigan Fm	
		Early	Osagian		Marshall Ss		Marshall Ss	
			Kinderhookian		Coldwater Sh		Coldwater Sh	
					Sunbury Sh		Sunbury Sh	
					Ellsworth Sh (western) / Berea Ss (eastern)		Ellsworth Sh (western) / Berea Ss (eastern)	
					Bedford Sh (eastern)		Bedford Sh (eastern)	
	Devonian	Late	Chautauquan		Antrim Sh	Upper Mbr	Upper Mbr	Antrim Sh
						Lachine Mbr	Lachine Mbr	
						Paxton Mbr	Paxton Mbr	
						Norwood Mbr	Norwood Mbr	
			Senecan		Squaw Bay Ls		Squaw Bay Ls	
		Middle	Erian	Traverse Gr	Thunder Bay Ls	Partridge Point Mbr	Traverse Ls	Traverse Gr
						Potter Farm Mbr		
						Norway Point Mbr		
					Alpena Ls	Four Mile Dam Mbr		
						Newton Creek Mbr		
					Long Lake Ls	Killians Mbr		
						Genshaw Mbr		
					Ferron Point Fm			
					Rockport Quarry Ls			
					Bell Sh		Bell Sh	
					Rogers City Ls		Dundee Ls	
					Dundee Ls			
			Ulsterian	Detroit River Gr	Anderdon Ls	Mackinac Breccia	Mackinac Breccia / Lucas Fm	Detroit River Gr
					Lucas Fm			
					Amherstburg Fm		Amherstburg Fm	
					Sylvania Ss		Sylvania Ss	
					Bois Blanc Fm		Bois Blanc Fm	
		Early			Garden Island Fm		Garden Island Fm	
	Silurian	Late	Cayugan	Bass Islands Gr	Rasin River Dol		undifferentiated	Bass Islands Gr
					Put-in-Bay Dol			
					St. Ignace Dol			
				Salina Gr	Pte. aux Chenes Fm		Salina G Unit	Salina Gr
							Salina F Unit	
							Salina E Unit	
							Salina D Unit	
							Salina C Unit	
							Salina B Unit	
							Salina A-2 Carb	
							Salina A-2 Evap	
							Ruff Fm	
							Salina A-1 Evap	
							Cain Fm	
		Middle	Niagaran	Engadine Gr	Bush Bay Fm		Guelph Dol	Niagara Gr
					Rapson Creek Fm			
					Rockview Fm		Lockport Dol	
				Manistique Gr	Cordell Fm		undifferentiated	Manistique Gr
					Schoolcraft Fm			
				Burnt Bluff Gr	Hendricks Fm	Fiborn Ls Mbr	undifferentiated	Burnt Bluff Gr
					Byron Fm			
					Lime Island Fm			
		Early	Alexandrian	Cataract Gr	Cabot Head Sh		Cabot Head Sh	Cataract Gr
					Manitoulin Dol		Manitoulin Dol	
	Ordovician	Late	Cincinnatian	Richmond Gr	Big Hill Fm		Queenston Sh	Richmond Gr
					Stonington Fm	Ogontz Mbr	Utica Sh	
						Bay de Noc Mbr		
					Bill's Creek Sh			
		Middle	Mohawkian		Collingwood Sh		Collingwood Sh	
					Trenton Fm	Groos Quarry Mbr	Trenton Fm	
						Chandler Falls Mbr		
					Black River Fm		Black River Fm	
			Chazyan		<unconformity>		Glenwood Fm	
							St.Peter Ss	
			Whiterockian					
		Early	Canadian		Au Train Fm		Foster Fm	Prairie du Chien Gr
							undifferentiated	
	Cambrian	Late	Trempealeauan		<unconformity>		Trempealeau Fm	
			Franconian		Munising Fm	Miner's Castle Mbr	Franconia Fm	Munising Gr
			Dresbachian			Chapel Rock Mbr	Galesville Ss	
							Eau Claire Fm	
						Basal Cgl	Mount Simon Ss	
Precambrian	Middle Proterozoic Eon				Jacobsville Ss		Pre-Mt. Simon Clastics	
				Oronto Gr	Freda Ss			
					Nonesuch Sh		Precambrian Crystalline Basement Complex	
					Copper Harbor Cgl			
	Archean to Middle Proterozoic Eons				Precambrian Crystalline Basement Complex			



RELATED TERM CORRELATION

STRATIGRAPHIC POSITION	RELATED TERMS
Ionia Fm	Jurassic Red Beds
Michigan Fm	Clare Dolomite, Brown Lime, Stray Dolomite, Stray Sandstone, Stray-Stray Sandstone, Stray-Stray-Stray Sandstone, Triple Gyp
Coldwater Sh	Coldwater Red Rock, Speckled Dolomite, Wier Sand
Antrim Sh	Charlton Black Shale Member, Elltrim, Chester Black Shale Member, Upper Black Shale, Light Antrim, Lower Black, Lower Antrim Middle Antrim, Middle Gray Antrim, Dark Antrim, Middle Gray Shale, Unit 1A, Unit 1B, Unit 1C, Crappo Creek Grey Shale Member
Dundee Ls	Reed City Member/Dolomite/Anhydrite
Lucas Fm	Freer Sandstone, Horner Member, Iutzi Member, Massive Salt/Anhydrite, Sour Zone, Big Anhydrite, Richfield Zone/Member/Sandstone, Big Salt
Amherstburg Fm	Filer Sandstone, Meldrum Member, Black Lime
St. Ignace Dolomite	Salina H Unit
Salina B Unit	Big Salt, B Salt
Ruff Formation	Salina A-1 Carbonate, Rabbit Ears Anhydrite,
Cain Fm	Salina A-0 Carbonate
Guelph Dolomite	Brown Niagara, Niagaran Reef, Pinnacle Reef, Engadine Dolomite
Lockport Dolomite	Gray Niagara, White Niagara
Burnt Bluff Gr	Clinton Formation
Trenton Fm	Cap Dolomite
Black River Fm	Van Wert Zone, Sneaky Peak, Black River Shale
Glenwood Fm	Goodwell Unit, Zone of Unconformity
St. Peter Sandstone	Bruggers Sandstone, Jordan Sandstone, Knox Sandstone, Massive Sand
Prairie du Chien Gr	Foster Formation, New Richmond Sandstone, Lower Knox Carbonate, St. Lawrence Formation, T-PDC, Oneota Dolomite, Brazos Shale
Trempealeau Fm	Lodi Formation
Galesville Ss	Dresbach Sandstone
Pre-Mt. Simon Clastics	Precambrian "Red Beds"

LEGEND

Sandstone	**Limestone**
Limey	Shaley
Shaley	Sandy
Dolomitic	**Dolomite**
Conglomeritic	Sandy
Siltstone	Shaley
Shale	**Glacial Drift**
Sandy	**Anhydrite/Gypsum**
Limey	**Reefs/Bioherms**
Dolomitic	**Basement Rocks**
Salt	**Coal Bed**

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Figure B.7-1
Michigan Stratigraphic Column

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Scale: NTS	Date: September 2019	
2019_CFL_EGLE_Fig_B.7-01.pdf	By: WEK	Checked: CW

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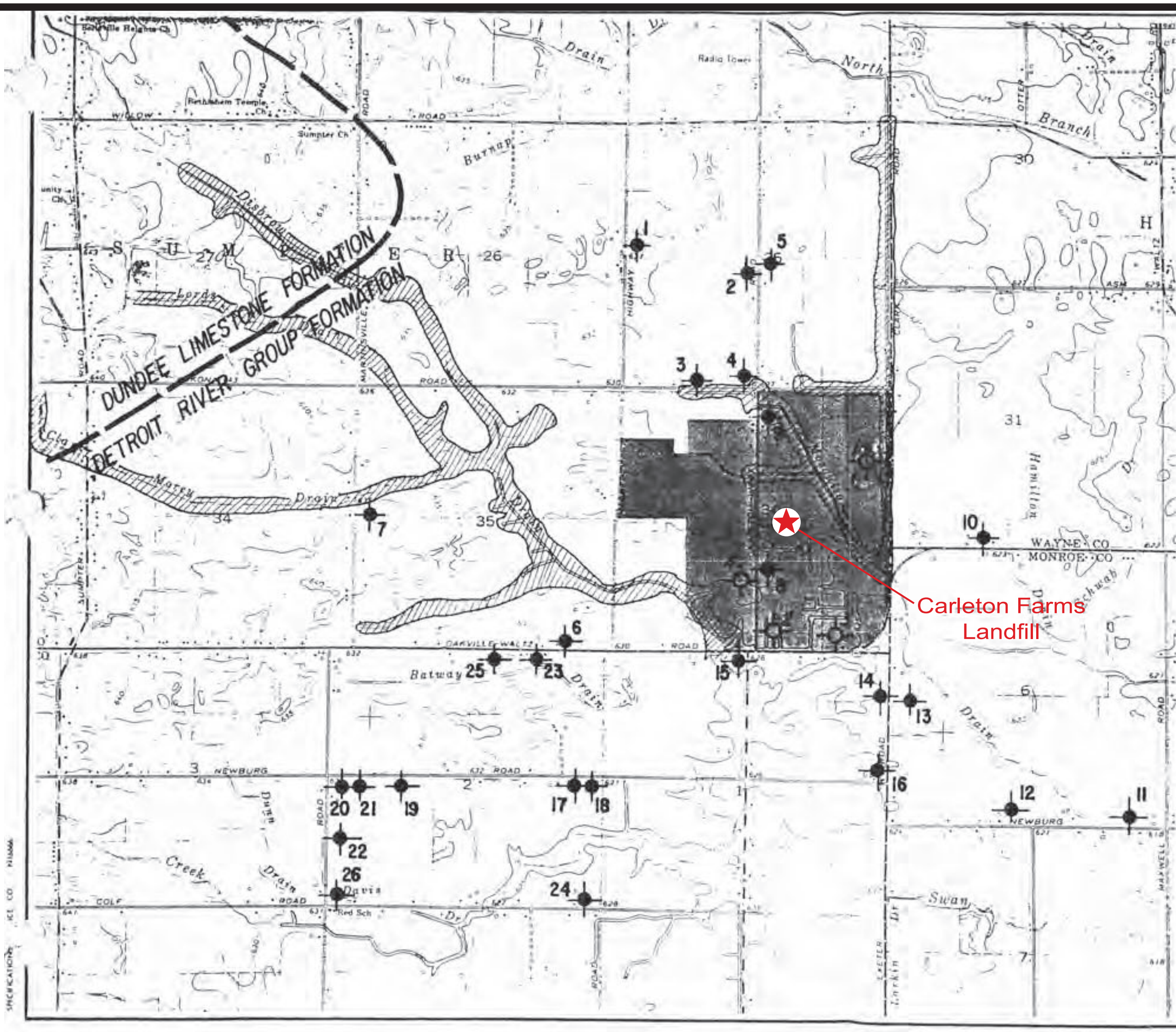

NORTH

SCALE FEET

0 1000 2000 4000

LEGEND

PROPOSED ENVIRONMENTAL MANAGEMENT SYSTEMS LANDFILL SITE (Property under control as of December 20, 1988)

Approximate Location of WATER WELL of Record

SUBCROP CONTACT (Between the Dundee Limestone Formation and the Detroit River Group Formation)

Approximate Location of 100-YEAR FLOOD PLAIN BOUNDARY as determined by the Federal Emergency Management Agency (FEMA).

Approximate location of WATER WELL Observed by Neyer, Tiseo & Hindo, Ltd. (record not available)

NOTES

- The position of the contact between the Dundee Limestone and the Detroit River Dolomite Formations was determined from available test boring information and geologic data provided in : Report on Investigation 3 - Geology for Land and Groundwater Development in Wayne County, Michigan. By A. J. Mozola, Published in 1969 by the MDNR; Groundwater Quality in Southeast Michigan - Considerations for Area Wide Water Quality Planning, By Robert F. Gorman, Published in 1978 By the Southeast Michigan Council of Governments.
- 100-Year Flood Plain Boundaries were interpreted from Flood Insurance Rate Maps (FIRM) Prepared by the Federal Emergency Management Agency, (FEMA) for Sumpter Township, Michigan. Boundaries shown are approximate.
- This map was taken from the USGS 7.5 Minute Carleton, Michigan Quadrangle.

REGIONAL HYDROLOGY & GEOLOGY

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NEYER, TISEO & HINDO, LTD.
CONSULTING ENGINEERS AND GEOLOGISTS
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PROJECT NO.: 88468 ow	DRAWN BY: Guy	DATE: 1-18-89
SCALE: As Shown	CHECKED BY: RLB	SHEET 1 OF 1

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Figure B.7-2
Local Bedrock Subcrop Map,
Carleton Farms Landfill
2019 Permit Application

Scale: See Figure Scale	Date: September 2019	
2019_CFL_EGLE_Fig_B.7-02.pdf	By: WEK	Checked: CW

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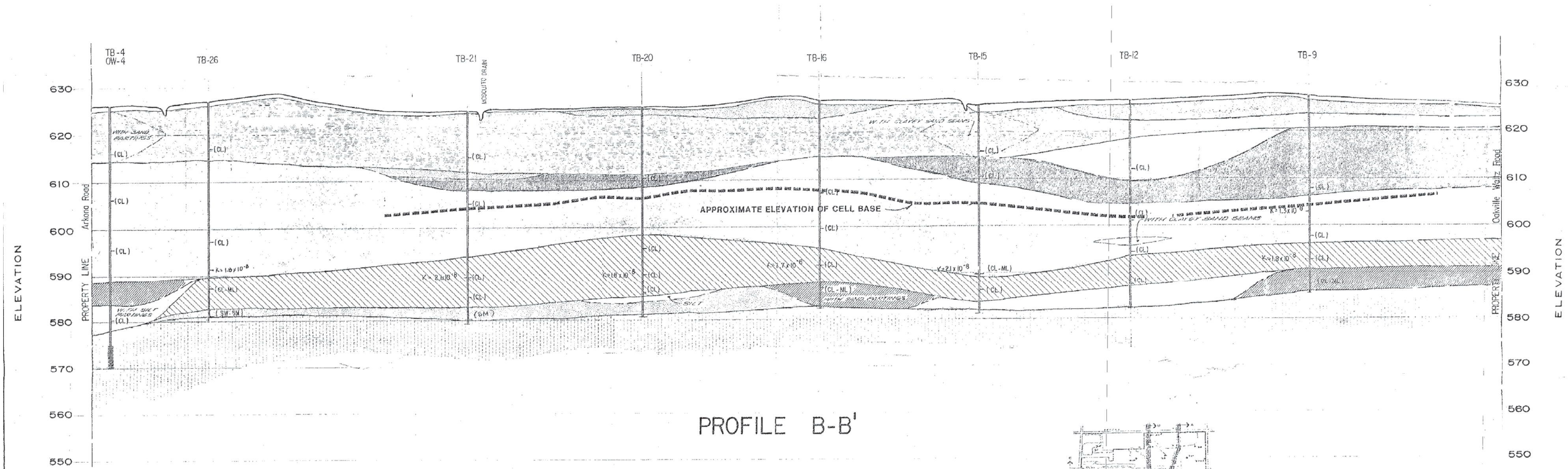


LEGEND

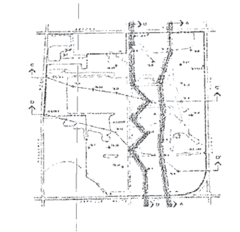
- TOPSOIL: Light Brown to Dark Brown SILTY SAND to SILTY CLAY
- Loose to Compact Brown to Gray SAND to SILTY SAND (with variations as shown on profile.)
- Stiff to Hard Mottled Brown and Gray SILTY CLAY with Little to Some Sand and Trace of Gravel (with variations as shown on profile)
- Hard Gray SILTY CLAY with Some Sand and Trace of Gravel
- Stiff to Very Stiff Gray SILTY CLAY with Little to Some Sand and Trace of Gravel (with variations as shown on profile)
- Stiff to Very Hard Gray SANDYCLAY with Some Silt and Trace of Gravel.
- Soft to Medium Gray SILTY CLAY with Trace to Some Sand and Trace of Gravel (with variations as shown on profile)
- Hard, Moderately to Closely Factured Tan to Gray Luminated to Massive LIMESTONE with Occasional Vugs
- $K: 2.0 \times 10^{-8}$ cm/sec COEFFICIENT OF VERTICAL PERMEABILITY
- (CL) UNIFIED SOIL CLASSIFICATION
- LOCATION OF OBSERVATION WELL SCREEN

NOTES

- For the location of Geologic Profiles also see Plate 1 - Test Boring and Observation Well Location Plan.
- The information presented in the subsurface profile is generalized. Geologic contacts shown on this plate have been inferred from test boring data and may be different from that shown. For actual subsurface conditions at specific locations see the individual Logs of Test Boring.
- Reported permeabilities were determined by a Falling Head Test in a Consolidometer Cell. For additional information on soil properties, see the Tabulation of Laboratory Test data sheets in Appendix B.
- Unified [illegible] Classification designations were assigned according to ASTM Test Method [illegible]-85.

VERTICAL SCALE FEET

HORIZONTAL SCALE FEET



PROFILE LOCATION MAP
Not to Scale

NOTE
THIS PLATE SUPERCEDES ANY EARLIER VERSION CHANGES WILL BE LISTED IN THE REVISION BLOCK

GENERALIZED GEOLOGIC PROFILES A-A' & B-B'

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PROJECT NO 88482 GW	DRAWN BY	DATE 12-19-88
SCALE As Shown	CHECKED BY RLB	SHEET 1 OF 1

Plate 4

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Figure B.7-3
Local Surficial Cross Section B-B',
Carleton Farms Landfill
2019 Permit Application

Scale: See Figure Scale	Date: September 2019	
2019_CFL_EGLE_Fig_B.7-03.pdf	By: WEK	Checked: CW

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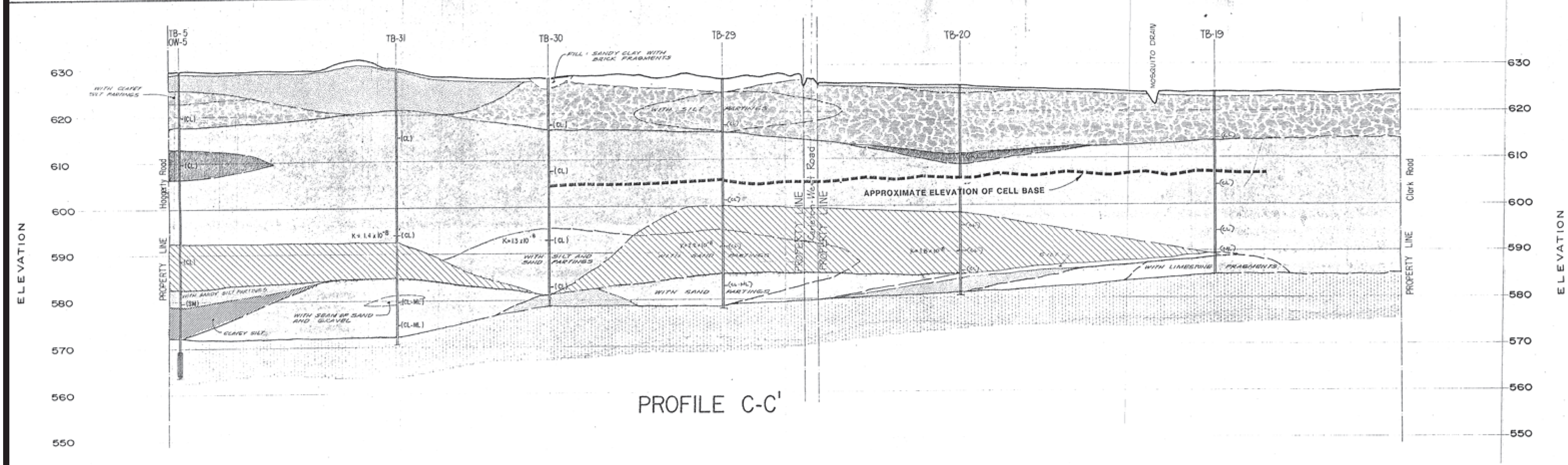


LEGEND

- TOPSOIL Light Brown to Dark Brown SILTY SAND to SILTY CLAY
- Loose to Compact Brown to Gray SAND to SILTY SAND (with variations as shown on profile)
- Stiff to Hard Mottled Brown and Gray SILTY CLAY with Little to Some Sand and Trace of Gravel (with variations as shown on profile)
- Hard Gray SILTY CLAY with Some Sand and Trace of Gravel
- Stiff to Very Stiff Gray SILTY CLAY with Little to Some Sand and Trace of Gravel (with variations as shown on profile)
- Stiff to Very Hard Gray SANDY CLAY with Some Silt and Trace of Gravel. (with variations as shown on profile)
- Soft to Medium Gray SILTY CLAY with Trace to Some Sand and Trace of Gravel (with variations as shown on profile)
- Hard Moderately to Closely Factured Tan to Gray Laminated to Massive LIMESTONE with Occasional Vugs

$K=2.0 \times 10^{-8}$ cm/sec COEFFICIENT OF VERTICAL PERMEABILITY

(CL) UNIFIED SOIL CLASSIFICATION

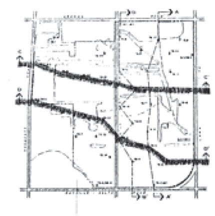
LOCATION OF OBSERVATION WELL SCREEN

NOTES

- For the location of Geologic Profiles also see Plate 1 - Test Boring and Observation Well Location Plan.
- The information presented in the subsurface profile is generalized. Geologic contacts shown on this plate have been inferred from test boring data and may be different from that shown. For actual subsurface conditions at specific locations see the individual logs of Test Boring.
- Reported permeabilities were determined by a Falling Head Test in a Consolidometer Cell. For additional information on soil properties, see the Tabulation of Laboratory Test data sheets in Appendix B.
- Unified Soil Classification designations were assigned according to ASTM Test Method D-2487-85.

VERTICAL
SCALE FEET
0 5 10 20

HORIZONTAL
SCALE FEET
0 100 200 400



PROFILE LOCATION MAP
Not to Scale

NOTE
THIS PLATE SUPERCEDES ANY EARLIER VERSION CHANGES WILL BE LISTED IN THE REVISION BLOCK

REVISED LOCATION OF CELL BASE AND TEST BORINGS 29, 20, 19 10-31-89.

GENERALIZED GEOLOGIC PROFILES C-C' & D-D'

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PROJECT NO. 88498 GW	DRAWN BY Guy	DATE 12-19-88
SCALE As Shown	CHECKED BY R L B	SHEET 1 OF 1

Plate 5

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Figure B.7-4
Local Surficial Cross Section C-C',
Carleton Farms Landfill
2019 Permit Application

Scale: See Figure Scale	Date: September 2019	
2019_CFL_EGLE_Fig_B.7-04.pdf	By: WEK	Checked: CW

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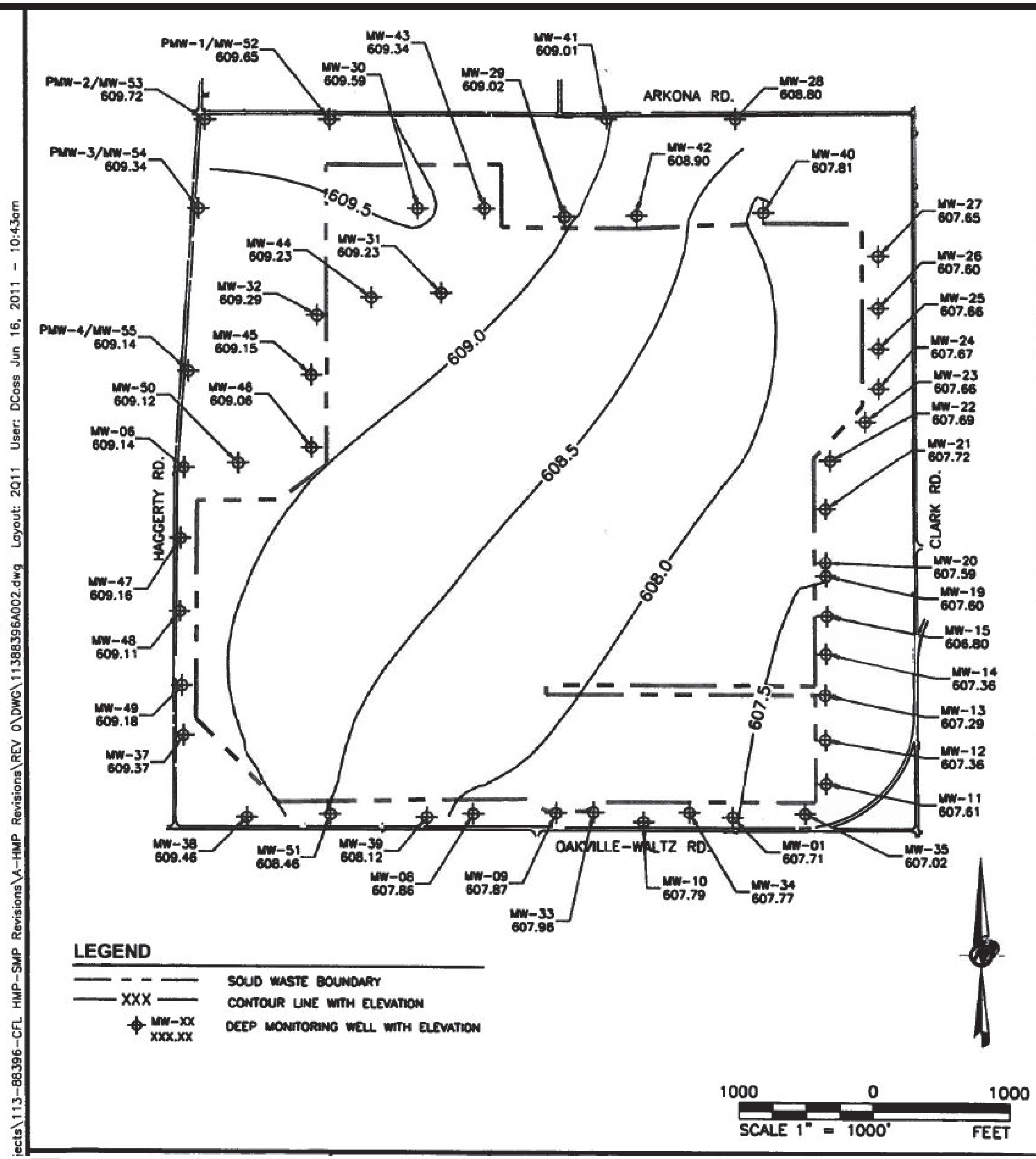

Golder Associates Michigan	SCALE	AS SHOWN	TITLE
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	DESIGN	N/A	
	CADD	DJC	
FILE No. 11388396A002	CHECK	CLP	REPUBLIC SERVICES, INC.
PROJECT No. 113-88396 REV. 0	REVIEW	SLP	FIGURE 3

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Figure B.7-5
Potentiometric Surface Map,
Carleton Farms Landfill
2019 Permit Application

Scale: See Bar Scale	Date: September 2019	
2019_CFL_EGLE_Fig_B.7-05.pdf	By: WEK	Checked: CW

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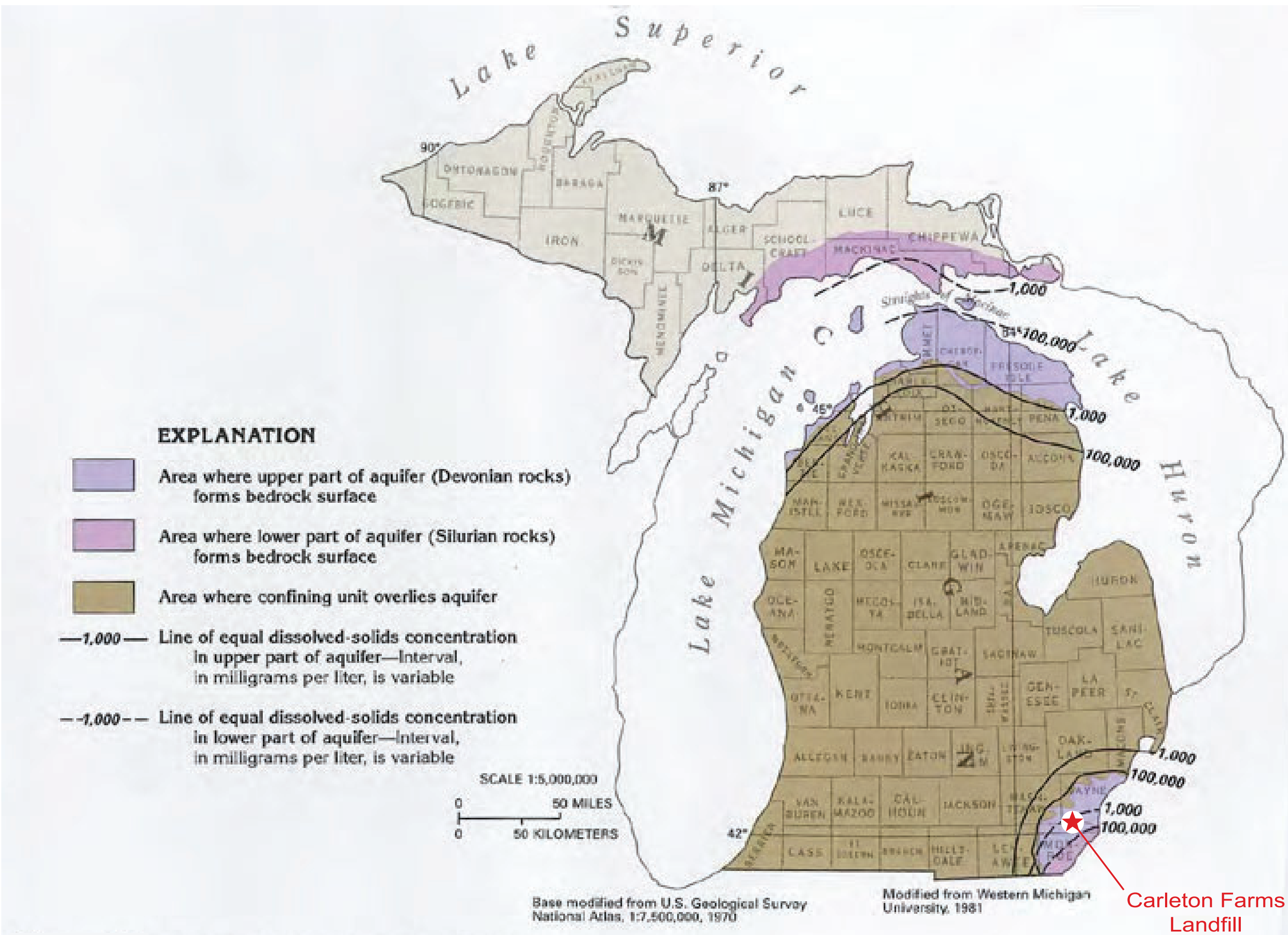

The Silurian–Devonian aquifer in Michigan contains potable water in outcrop areas, but dissolved-solids concentrations rise to over 1,000 milligrams per liter near the periphery of the overlying confining unit and rapidly increase to brine concentrations downgradient.

REPUBLIC SERVICES

Figure B.7-6
Water Quality Data,
Silurian-Devonian Aquifer
2019 Permit Application

Scale: See Figure Scale	Date: September 2019	
2019_CFL_EGLE_Fig_B.7-06.pdf	By: WEK	Checked: CW

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B.8 Geologic maps and stratigraphic cross sections of the local and regional geology.

B.8.1 Regional Geology

B.8.1.1 General History of the Michigan Basin

The Michigan Basin is an intracratonic basin that occupies an area of about 80,000 mi^2 (Catacosinos et al., 1991) (Figure B.8-1). The basin is nearly circular and was created by four different styles of subsidence: trough-shaped, regional tilting, narrow basin-centered and broad basin-centered (Howell and van der Pluijm, 1999). The basin is centered on Michigan's southern peninsula and is generally separated from other nearby basins by major arches. The basin is characterized structurally by several Paleozoic anticlines that trend northwest-southeast, which some authors (e.g., Wood and Harrison, 2002) present in association with basement faults or lineaments.

The Michigan Basin contains as much as 16,000 feet of sedimentary rock, covered by up to 1,200 feet of Pleistocene-age glacial drift (Catacosinos et al., 1991). Figure B.7-1 presents the stratigraphic column of Michigan, and Figure B.8-2 is a Geologic Map of Michigan, showing the subcrop configuration of strata in the Michigan Basin and the location of the Carleton Farms Landfill, referred to hereafter as CFL, or the Site. The Precambrian basement underlying the Michigan Basin is part of the Superior Province, and is approximately 1.2 to 1.5 billion years old. About 5,000 feet of thickened Precambrian-age sedimentary rock occurs above basement along a north-south trending linear trend associated with a gravity anomaly that has been interpreted by Catacosinos, et al. (1991) and others to be a portion of a buried ancient rift system. Adjacent to this trend, Cambrian rocks occur above the crystalline Precambrian basement, as is the case at CFL.

A gradual marine transgression occurred through the Late Cambrian. Late Cambrian deposits including the Mt. Simon Sandstone, Eau Claire Formation, Dresbach(Galesville) Sandstone, and Franconia Formation are probably marine in origin, with the source of sedimentary material originating from northeast. By the end of the Cambrian Period, most of the United States was under water. This circumstance continued through the Ordovician in the Michigan Basin area. Cambrian-Lower Ordovician units were deposited within a northerly transgressing epicontinental sea; the units are predominantly siliciclastic and can be over 4,500 feet thick in the center of the basin.

The Lower Ordovician Trempealeau Formation and Prairie du Chien Group were also generally deposited in a marine environment. A minor regression preceded the deposition of the onshore/nearshore St. Peter Sandstone. Deposition of the offshore marine shale and carbonates of the Trenton and Black River Formations was followed by another regression, with an accompanying unconformity. The late Ordovician Richmond Group, which includes the Utica Shale, is composed of shale deposited in a deep water environment.

During the Silurian, the Michigan Basin was an interior sea surrounded by low-lying land areas that partially isolated the sea from other bodies of water. In the absence of a significant nearby source of clastic material, the main deposits of the Silurian were evaporite and reef deposits. The Middle Silurian Niagara Formation was deposited throughout the lower peninsula of Michigan, and is composed of carbonate reef deposits. Progressive isolation of the Basin with respect to water influx is evidenced by deposition of the Salina Formation, which contains evaporates including anhydrite and halite that were deposited in the relatively restricted inland sea. During the Silurian, over 3,000 feet of sediment was deposited in the center of the Michigan Basin.

The base of the Devonian Period is represented by an unconformity as the seas regressed and land emerged, which was followed by transgression and subsequent deposition of carbonate-rich sequences through the early and middle Devonian. The Devonian-age Detroit River Group consists of carbonates and evaporites, with some shale. The Dundee Formation, which consists of carbonates, was deposited after the Detroit River Group. In the case of the CFL location, all sedimentary units above the Lucas Formation (Figure B.7-1) were removed by erosion and are not present at the site. The Lucas Formation is the bedrock formation that occurs at or near ground level in the CFL area, overlain by alluvium and glacial sediments.

B.8.1.2 Regional Structural Geology

The CFL is located on the southeastern flank of the Michigan Basin as shown on Figures B.8-1 and B.8-2. The Michigan Basin resulted from epeirogenic down warping during the Paleozoic Era, and subsidence of the basin controlled the deposition of sedimentary units during the Paleozoic. Each Paleozoic unit dips toward the center of the basin, and generally thickens basin-ward. The basin extends into northwest Ohio and northeast Indiana and covers all of the Lower Peninsula of Michigan. The structural axis of the Findlay Arch is southeast of the Basin and the axis of the Kankakee Arch is to the southwest. Regional dip on the top of the Precambrian basement in the Carleton area is to the northwest at about 60 feet per mile.

Precambrian geomorphic features are present within Michigan, and provide insight as to the varying structural features evidence in the CFL area. As shown in Figure B.8-3a, the midcontinental rift extends in through the central portion of the Michigan Basin and underlies the current sedimentary column. To the east of this paleorift lies the Grenville Province (aka the Grenville Metamorphic Front/Province or Grenville Tectonic zone), which is the “continent-ward boundary of deformation of the fold-and-thrust belt from the Grenville orogeny, the sequence of orogenic events from ca. 1.3–0.98 Ga”. (https://www.geosociety.org/gsatoday/science/G357A/article.htm#toclink2).

The sedimentary depositional centers of the Michigan Basin lie to the west of this feature. The CFL site occurs within the Grenville Zone or Province. As shown in Figure B.8-1, important structural features associated with this province are the Bowling

Green Fault Zone which lies over 10 miles southwest of the CFL, and the Howell fault, which occurs northwest of the area. Milstein (1989) also suggests that isopach variations in overlying Cambrian units reflect irregularities on the Precambrian surface: "prominent Precambrian features like the Washtenawa Anticlinorium in southeastern Michigan, and the Bowling Green Fault located along the Leawee and Monroe County boundary, are both reflected in the Cambrian sediments." The current northwest-southeast structural grain apparent in regional structural maps (e.g., Figure B.8-3) was imposed in late Mississippian to Pennsylvanian "possibly as the result of flexural foreland subsidence in response to the Alleghenian-Hercynian Orogeny…" (Catacosinos et al., 1991). These features extend to southeastern Michigan.

Wood and Harrison (2002) explored the occurrence and expression of faults within the Michigan Basin through mapping of post-Silurian sediments. They concluded that the "Michigan Basin is cut by numerous (12+) major faults lying below the glacial drift and below the topmost Jurassic sediments". The lineations generally trend northwest-southeast (Figure B.8-3b). These lineations are dominant features of the subsurface topography and are well documented, occurring as structural features expressed in units from at least the Late Devonian (Dundee time) to the Mississippian. Wood and Harrison (2002) state "These faults carve out [a] large depression in the Central Michigan Basin and appear to be responsible for shallow anticlines that hold or held a significant portion of the hydrocarbons in the Michigan Basin". The origin of these faults was attributed to deep-seated normal basement faults "rooted in the Precambrian rift sequence". Figure B.8-3b presents the location of these northwest-southeast trending features (Dundee Lineaments) presumably associated with basement faults.

B.8.1.3 Regional Stratigraphy

Figure B.7-1 presents the stratigraphic column for Michigan. Figures B.8-4 and B.8-5 are regional cross sections available from the literature, and show regional stratigraphic correlations and geologic structure across the state into the southeastern portion of the Michigan Basin.

B.8.1.3.1 Precambrian (Lower Confining Zone)

The Precambrian crystalline basement is described as primarily metasedimentary gneiss (mafic and felsic) formed by the metamorphism of igneous rock as well as shales, sandstones, carbonate and iron formations. Igneous intrusions may also occur within these units. The Precambrian basement is estimated to occur at approximately 3,827 feet below ground level (ft BGL) at the IW#1-36N location, or approximately 3,200 feet below mean sea level (ft BMSL) at the Site (Figure B.8-6), and serves as the lower Confining Zone. In southeast Michigan near the Site, the Precambrian dips at approximately 60 feet per mile to the northeast, toward the center of the Michigan Basin and may occur at least 14,000 feet or more below ground level near the basin center.

B.8.1.3.2 Cambrian and Lower Ordovician Systems (Injection Interval and Injection Zone)

The Cambrian is composed of the Mt. Simon Sandstone and the Munising Group that includes the Eau Claire Formation, Dresbach (Galesville) Sandstone, and the Franconia Formation. The Trempealeau Formation and Prairie du Chien Group are Lower Ordovician in age, and the St. Peter and Glenwood Formations are Middle Ordovician in age, where present. All units from the Glenwood through Mt. Simon Formation are included in the injection zone; the injection interval includes units the Franconia/Dresbach, Eau Claire, and the Mt. Simon Formation.

Units from the Franconia to the top of the Mt. Simon comprise the Munising Group, although various authors have also included the Mt. Simon in the Munising Group. For the purposes of this report, the Munising Group is assumed to consist of the Mt. Simon, Eau Claire, and Franconia/Dresbach Formations.

Mt. Simon Sandstone (Injection Interval)

The Mount Simon Sandstone (Mt. Simon) is a massive sandstone that is present in the subsurface throughout much of Ohio, Indiana, Illinois, and the lower peninsula of Michigan. Figure B.8-7 is an isopach of the Mt. Simon in the Michigan Basin, and Figure B.8-8 is a structure contour map constructed at the top of the Mt. Simon. The Mt. Simon is thickest within the central portions of the Basin, and reaches a thickness of approximately 1,240 feet in the Gratiot County region. The Mt. Simon thins dramatically to the east side of the state where it is approximately 200-250 feet thick in areas of Wayne and Monroe county, and absent in Oakland county. At a close Mt. Simon data control point (i.e., the Romulus/EGT wells), the Mt. Simon is approximately 300 feet thick and occurs at approximately 4,240 feet BGL, noting that the depth to the top of the Mt. Simon is expected to be shallower at the CFL area due to changes in regional dip (i.e., approximately 3,500 feet BGL).

In the southern peninsula of Michigan, the Mt. Simon typically lies unconformably above the Precambrian Crystalline Basement Complex and is projected to occur at approximately 3,800-3,900 feet BGL at the Site. The Mt. Simon is described as a subrounded to rounded quartzitic sandstone that is generally fine to coarse grained and well sorted. It is pink to red, with a greater abundance of feldspar at the base of the unit. WMU (1981) states that “glauconite, anhydrite, and green shale are present in minor amounts with local dolomite cement”. Barnes et al. (2009) indicate that the Mt. Simon is composed of three basic units: a basal arkosic unit, a middle quartz arenite-glauconite unit, and an upper shale-rich unit that grades conformably into the Eau Claire Formation. Some authors and wellsite geologists may have attributed basal pre-Mt. Simon sediments (granite wash) to be part of the basal arkosic Mt. Simon unit.

Regional porosity development is generally related to the burial depth, with better porosity developed in areas with less overburden (Barnes et al. 2009). State-wide, literature has generally indicated that Mt. Simon porosity typically ranges from 4-20% and may also vary laterally where sandstones grade into more shale or carbonate-rich facies.

The Mt. Simon is a common target for fluid injection, and is under scrutiny as a potential target for CO_2 sequestration. WMU (1981) states that with respect to the Mt. Simon as a whole, regionally the “the permeable Cambrian quartz sandstone, siltstone, and arenaceous dolomite suitable for fluid injection comprise about 27% of the stratigraphic column”. Barnes et al. (2009) conclude that “The Mount Simon Sandstone in Michigan is an important saline reservoir target for geological sequestration of CO_2 in Michigan”. Various authors have concluded that the Mt. Simon has both the capacity to accept injectate and has “cap rocks” suitable to arrest vertical fluid migration.

Eau Claire Formation (Injection Interval)

The Eau Claire Formation (Eau Claire) occurs conformably above the Mt. Simon in the southern peninsula of Michigan, and consists of interbedded sandstones, siltstones, and shales may also include thinly bedded dolomites (Milstein, 1989). It is described as appearing similar to the Mt. Simon, particularly in lower portions where the two units are conformable and the contact is therefore somewhat gradational. In the center of the Michigan Basin, the Eau Claire is composed of up to 100% shale and dense siltstone, with the proportion of shale in the formation decreasing toward the basin margins.

The thickness of the Eau Claire varies considerably within the Michigan Basin. WMU (1981), states that the Eau Claire ranges from 0-1,500 feet thick in the Michigan Basin, with the thickest deposits occurring in the central portion of the Basin. Milstein (1989) believes there to be about 800 feet of Eau Claire in the central portion of the basin. Milstein (1989) mapped the Eau Claire showing a maximum thickness of over 800 feet near the central basin and thinning to less than 100 feet along the eastern margin of the state (Figure B.8-9). The Eau Claire is mapped by Milstein (1989, Figure B.8-9) as being approximately 250-275 feet thick at the Site, although this thickness likely incorporateds portions of the Mt. Simon Formation and is actually thinner than mapped by Milstein.

The top of the Eau Claire occurs at about 3,000 feet BMSL (3,600 feet BGL) (Figure B.8-10) in southern Wayne and Monroe Counties, according to regional map data, local estimates are provided in Section B.8.2.2. The Eau Claire is included in the Injection Interval, and includes interbedded carbonates, shale, and other siliciclastic intervals.

Dresbach (Galesville) Sandstone and Franconia Formation (Injection Interval)

The Dresbach (Galesville) Sandstone is also thickest in the central portion of the Michigan Basin, reaching its greatest thickness of over 600 feet in Gladwin County (Figure B.8-11a). Regional data show the Dresbach to be approximately 50-150 feet thick in southern Wayne and northern Monroe counties. Site specific estimates are presented in Section B.8.2.2. The Dresbach is described as medium grained silicacemented sandstone that may have glauconite and dolomite, with some siltstone and shaley units present locally.

The Franconia Formation includes “a wide array of glauconitic dolomitic sandstone, shale, and sandy dolomite” that is sometimes indistinguishable from the underlying Dresbach Sandstone. At the CFL, these units are difficult to distinguish and thus referred to as the Franconia/Dresbach unit throughout this permit application. Milstein (1989) states that the Franconia is composed of a light pink to gray quartz sandstone that contains pyrite and abundant glauconite, but can be readily identified by gamma ray log. The Franconia has a maximum thickness of about 800 feet, and is estimated to be approximately 100-120 feet thick in the Site (Figure B.8-11b); local estimates are consistent with this regional data and are presented in Section B.8.2.2.

Trempealeau Formation (Injection Zone)

The Trempealeau Formation is Lower Ordovician in age and is a buff to light brown dolomite that can be sandy, shaly, and cherty, with some glauconite. Literature suggests that the formation is likely composed (from the top down) of the St. Lawrence, Lodi, and Jordan members (WMU, 1981). The St. Lawrence member is a sandy dolomite with dolomitic shales. The Lodi is a sandy dolomite with interbedded stringers of shale and sandstone, while the Jordan sandstone is fine grained quartz sandstone to sandy dolomite. This formation represents a transition between underlying sand-rich units and overlying carbonate rich intervals. Figure B.8-12 presents a regional isopach map of the Trempealeau Formation, and Figure B.8-13 presents a regional structural contour map. The Trempealeau Formation is approximately 100 feet thick below the Site area, and is more than 900 feet thick in the center of the Michigan Basin.

Prairie du Chien Group (Injection Zone)

The Prairie du Chien Group is Lower Ordovician in age, and consists of various layers primarily comprised of gray, sandy dolomite and dolomitic sandstone and includes the Shakopee [Foster] Formation as well as other major units identified by WMU (1981) as the Oneota Dolomite, New Richmond Sandstone, and Shakopee Dolomite. WMU (1981) states that in the subsurface “the entire Prairie du Chien Group has characteristics similar to dolomite”, and indicates that in some areas (near subcrop) the Prairie du Chien is porous. Smith, et al. (1993) described the Prairie du Chien Group as carbonate-dominated mixed carbonate siliciclastic sediments “deposited in and adjacent to shallow tropical seas that flooded most of the central North American craton during the Early Ordovician…[and] consists of sandy, silty and relatively pure dolomites and minor quartzarenites that underwent intermittent reworking by waves and unidirectional currents”. Smith et al. (1993) also state that “In the subsurface of the Michigan basin, dolomites of the Oneota Formation overlie silty-glauconitic dolomites of presumed Trempealeauan age, and are overlain by silty-sandy dolomites and dolomitic siltstone of the basal Shakopee [Foster] Formation”. The Shakopee is heterogeneous and consists of interbedded silty and sandy dolomites, with dolomitic siltstones, sandstones and shales. In the central Michigan Basin, Smith et al. (1993) state that the Shakopee is overlain by shales of varying thickness, that in turn are overlain by the St. Peter Sandstone. Milstein (1983) mapped the occurrence of the Prairie du Chien in the Michigan Basin, and showed that this formation is likely nearly absent in the CFL area, as verified by local well data (Section B.8.2.2).

B.8.1.3.3 Middle and Upper Ordovician Units (Injection Zone and Upper Confining Zone)

St. Peter Sandstone/Glenwood Formation (Injection Zone)

The St. Peter Sandstone occurs unconformably above the Prairie du Chien, and is present in northern portions of the Michigan Basin. The St. Peter is mapped as absent in southern Michigan. The Glenwood Shale is dolomitic and sandy shale that occurs in the northwestern portion of the Michigan Basin. It thins to the east and is a greenish-grey shale in central Michigan. It is persistent and mappable throughout the Basin but typically is no greater than 20 feet thick. WMU (1981) suggests that this unit may serve as a Confining Zone, as it is “thought to be a barrier to the movement of hydrocarbons from the Black River Group into the underlying Prairie du Chien and Cambrian units”.

Black River/Trenton Groups (Upper Confining Zone)

The Black River Formation is composed of thick, undifferentiated dense brown/grey micritic limestones with cherty intervals and an altered volcanic ash layer called the Black River Shale. This shale is a thick yet distinctive bed, of limited extent, occurring in southern Michigan. Near outcrop, the Black River Formation may produce water from solution joints/fractures, but is “quite impermeable except where it has been dolomitized” in areas away from subcrop (WMU, 1981). The Trenton Formation consists of several hundred feet of light brown to brown limestone. It is 200-450 feet thick across the Michigan Basin. WMU (1981) states that “although the Trenton limestones are relatively impermeable, the possible presence of fractures and dolomitized zones could preclude its use as confining layer”. The principle porosity zones are in areas of dolomitization. The Trenton-Black River Formation interval is approximately 700-800 feet thick in the Site area, based upon well logs, and was the subject of early oil exploration in the area. Figure B.8-14a is a structure contour map constructed on the top of the Trenton, Figure B.8-14b is an isopach thickness map of the Trenton, and Figure 8-14c is an isopach thickness map of the Black River. Note that Sumpter Field is a one-well Trenton field located northwest of the site; the single well produced oil for less than two years and was plugged and abandoned in 1947.

Richmond Group/Utica Shale (Upper Confining Zone)

The Richmond Group unconformably overlies the Trenton and Black River Formation. Regionally, it contains the Collingwood Shale and Utica Shale. The Collingwood can also be a shaly limestone but the formation is not reported to be present in southern portions of the State. The Trenton-Richmond Group (i.e., Utica Shale) stratigraphic boundary is “a widely recognized and traceable stratigraphic boundary throughout the basin, well-marked on both petrophysical and lithologic logs and also visible seismically. It is commonly used as a datum for structure contour maps and is assumed to be a chronostratigraphic surface” (WMU, 1981). Note that various authors disagree whether the Trenton-Utica contact is conformable.

The Utica Shale is upper Ordovician in age and records the influx of argillaceous mud into the depositional system. The Utica is a hard, dark gray to greenish black calcareous shale that is present throughout the Michigan Basin (WMU, 1981). Thickness varies from 140 to over 400 feet thick (Figure B.8-15), and it is identified in this figure as being approximately 300-350 feet thick in the site area based on regional information, although this thickness likely incorporations shales within the overlying Cincinnatian. WMU (1981) states that “the very low permeability of this rather thick shale coupled with the fact that it forms the seal on known hydrocarbon traps indicates that it is an excellent confining layer”. The Utica Shale is the uppermost unit of the Upper Confining Zone.

The Upper Cincinnatian Group overlies the Utica shale. This Group consists of interbedded shales and carbonates, and is particularly shale-rich within the 200 or more feet that overlies the Utica Shale in the CFL area, based on well log data in the area.

Clinton-Cataract Group

The Clinton-Cataract Group occurs atop the Richmond Group, and consists of the upper Cabot Head Shale and lower Manitoulin Dolomite. The Cabot Head is composed of shale. The Manitoulin is buff to light brown dolomite, locally cherty with interbedded shale or shaly dolomite (Ells, 1967).

B.8.1.3.4 Silurian Units

Silurian units occur throughout Michigan and specifically in the Site area. The presence of low permeability units like shales and salts within the Silurian serve to impede vertical fluid movement.

Niagara Group

Matzkanin, et al. (1977) summarized the geology of the Niagara, stating “Niagara rocks in the subsurface are predominantly dolomites and limestones with scattered regional occurrences of cherty zones and thin shale beds. These rocks range in thickness from less than 100 feet in the basin interior to more than 1,000 feet at the basin margin… pinnacle reef complexes [occur] a few miles basin-ward from the thick carbonate bank. Reefs, reef associated sediments, and biostromes occur at various stratigraphic levels within the Salina-Niagara Group.” Data presented in WMU (1981) suggest that the CFL is located in the carbonate bank area, and is upwards of 500 feet thick in the site area. Niagaran production from the Northville Field occurs over 20 miles north of the CFL location.

Salina and Bass Island Groups

WMU (1981) states that the Salina Group is a "thick sequence of carbonate, anhydrite, silt and shale" that is restricted in areal extent to the approximate location of the Niagara Formation. The unit grades upward from the Basal "A" member (A-1 Evaporite, A-1 Carbonate, A-2 Evaporite and A-2 Carbonate) through F member, and is composed of interbedded shales, limestones and salts. Data indicate that the Salina Group as a whole may be several hundred feet thick in the CFL area, although anhydrite rather than salts appears to be the primary evaporite (WMU, 1981).

The Bass Islands Group conformably overlies the Salina. The Bass Islands in the Michigan Basin generally consists of dense, buff dolomite and the upper part is sparsely oolitic. Lower in the section, gray argillaceous dolomites, shaley dolomites, and brown beds are present (Ells, 1967). WMU, (1981) states that the Bass Islands is described as a thick sequence of fine-grained dolomites that has floating anhydrite and celestite crystals, as well as some salt in central portions of the Michigan Basin. Regional data suggest the Bass Islands Group ranges from 0-750 feet thick in the Basin center, and is about 100-200 or more feet thick in the Site area.

B.8.1.3.5 Devonian – Mississippian Units

Devonian-aged units present in the area include the Bois Blanc Formation, Sylvania Sandstone, and Detroit River Group. Note that well data often identify the Dundee Formation as subcrop in the Wayne and Monroe County areas, but recent geologic data indicate that the Dundee is likely absent by erosion, with the Lucas Formation of the Detroit River Group being the youngest bedrock in the area exposed below the overlying glacial material.

Detroit River Group

WMU (1981) states that the Detroit River Group includes the Garden Island, Bois Blanc, Sylvania, Amherstburg, and Lucas Formations. The Detroit River Group as a whole is about 360 feet thick in the Site area. The Bois Blanc is composed of dolomite and cherty dolomites, with upper limestone-rich intervals. The Sylvania is sandstone, composed of well-rounded and sorted fine to medium grained quartzitic sandstone with thick chert and dolomitic intervals that is present in northwestern areas of the Basin. The Sylvania is identified in at least one local water well, and outcrops to the east of the Site. The Bois Blanc-Sylvania interval is approximately 100-150 feet thick near CFL based on regional data. The Amherstburg is a dark brown to black carbonaceous limestone that is present in most of the Michigan Basin. It is poorly bedded and dense, and may be present in the site area, although not specifically identified in local well data.

While the Detroit River includes the above formations, WMU (1981) indicates that it is "general practice" to only call that portion of the column between the top of the Amherstburg and Dundee the "Detroit River" and WMU (1981) states this portion of the column is sometimes referred to as the "Lucas Formation". This portion of the column includes the Richfield Member, which is a sequence of interbedded limestone, dolomite and anhydrite with minor amounts of sand, a massive anhydrite unit, and the Horner Evaporite composed of interbedded anhydrite, limestone, and salt. The Lucas Formation is mapped as subcropping below the CFL area. Figure B.8-16 presents local bedrock below the site.

All units above the Detroit River are absent at the site due to erosion. Note that some geologic logs identify the occurrence of the Dundee Limestone, but state geologic maps indicate that the Lucas Formation (i.e., lower Detroit River) subcrops below overlying alluvium and glacial sediments in the Wayne and Monroe County areas.

B.8.1.3.6 Alluvium/Glacial Drift

Alluvium and glacial material cover the bedrock below the CFL area. Figure B.8-17 is a generalized regional isopach of the Glacial Drift showing that the Drift is approximately 50 feet thick at the Carleton Farms location in Wayne County. Alluvium plus glacial material thickness may range from 24 feet to over 74 feet locally. Alluvium generally consists of clay, silt, sand and gravel; glacial deposits occur below the alluvium, however most of the county is covered in lacustrine [lake] deposits composed primarily of clay and sand (Apple and Reeves, 2007). Figure B.8-18 presents a map of surficial deposits in the CFL area.

B.8.1.4 Regional Hydrology

WMU (1981) provided an evaluation of regional groundwater systems in Michigan, and assigned Wayne and Monroe counties to the Southeast Southern Peninsula Region 1. According to this source, while most wells in these two counties produce from overlying alluvium and glacial material, upwards of 10% produce from bedrock units, including (where present) the Traverse, Dundee, Detroit River, and Sylvania Sandstone, as well as a few wells in deeper Silurian units such as the Bass Islands and Salina Group.

B.8.1.5 Regional Seismicity

The CFL is in a USGS designated minor seismic risk area (USGS, 2017). The site area has a peak acceleration of 4-6 percent g (Figure B.8-19), with a 2% probability of exceedance in 50 years. Further, the 2018 one-year model prepared by USGS (earthquake.usgs.gov/hazards/induced/index.php#2018USGS) identified the state of Michigan as having a less than 1% probability of minor damage ground shaking, including induced seismicity events such as those that occur in Oklahoma and Kansas. The University of Michigan (2015) indicated that the most recent earthquake with a magnitude greater than 4.5 occurred more than 60 years ago on August 9, 1947 near the town of Coldwater. It damaged chimneys and cracked plaster over a large area of south-central Michigan and affected a total area of about 50,000 square miles, including points north to Muskegon and Saginaw and parts of Illinois, Indiana, and Wisconsin. Since 2008, four earthquakes have been detected in southern Michigan, including two in southern Michigan that includes one northeast of Union City and another south of Galesburg. Figure B.8-20 shows that over the past 100 years, 14 earthquakes have occurred regionally, typically with a magnitude of 3.5 or less have occurred regionally, with all occurring over 20 miles from the CFL area. See Section B.8.3.8 for additional information.

B.8.2 Local Geologic Analysis

As shown on Figure B.4-1, summarized in Table B.4-1, and discussed in Section B.4, five wells partially penetrate the upper portion of the confining zone (Trenton and Utica Formations) within the AOR, but no wells fully penetrate through the Black River Formation to the injection interval within a two-mile radius around the CFL property boundary.

The nearest Class I wells penetrating to the Mt. Simon with well data, including test and core information and well logs, are two permitted and one plugged Class I Non-Hazardous Disposal wells owned by Environmental Geo-Technologies (EGT; previously Environmental Disposal Systems, Inc. [EDS]) in northern Wayne County. The two active wells are located in T3S R9E Section 12 (EPA Permit Nos. MI-163-1W-C010 for Well #1-12 and MI-163-1W-C011 for Well #2-12 issued in 2012). The plugged and abandoned well (EGT Well #1-20) is located in T3S R9E Section 20. Table B.8-1 summarizes pertinent information about these wells. The #1-12 and #2-12 wells are located approximately 11 miles northeast of the CFL site; well #1-20 is located approximately 7.5 miles northeast of the CFL site.

Table B.8-1. Location of Nearby Mt. Simon Disposal Wells

Mt. Simon Well Location	Formal Well Name on Well Log	Well Name this Report
T3S R9E Sec 12	Environmental Disposal Systems EDS 1-12	EGT or EDS Well #1-12
T3S R9E Sec 12	Environmental Disposal Systems EDS 2-12	EGT or EDS Well #2-12
T3S R9E Sec 20	Environmental Disposal Systems #1	EGT or EDS Well #1-20

Figure B.8-21 presents a cross section constructed using Mt. Simon wells closest to the CFL area. Figure B.8-22 presents the Injection and Confining Zone generalized type log for the CFL site based upon EDS #1-12 well log data.

Local isopach and structure contour maps were generated for formations of interest in the Site area from available regional data. Maps were constructed based on a combination of well log picks and formation tops from the Michigan Department of Environmental Quality well database. Text discussion for units includes formation thickness and formation top information derived from wellsite geologist formation descriptions, but every value may not always directly correspond to the values presented on the associated structure contour and isopach maps. These small discrepancies are due to different methodologies for “picking” formations (i.e., during drilling vs. well logs). Significant differences between the data sources are identified and discussed in the text as appropriate, but minor variations of a few feet do not impact conclusions and are not explained further in subsequent sections of this document.

B.8.2.1 Local Structural Geology

Regional structure contour maps are presented in Figures B.8-6, B.8-8, B.8-10, B.8-13, and B.8-14a. Local structure contour maps were constructed based on these maps with refinement using additional well data available from the EGT and other wells. Local maps are presented as they are discussed in subsequent sections. These maps were generally constructed using 50 foot contour intervals or alternates as appropriate for clarity of presentation. Consistent with regional characterization discussed in Section B.8.1, the analyses and mapping indicate that there are no major or mappable structural features within the Site area. Site-specific data also indicate that there are no mappable faults that transect the Injection Zone or Confining Zone locally within the AOR. That is, the Injection Zone and Confining Zone are laterally continuous, with no abrupt changes in thickness or lithology within a 5-mile radius of the Site. Structural analyses are dependent upon availability and accuracy of regional data as presented in the public record.

A local structure contour map was constructed at the top of the Mt. Simon using historical regional data presented in the EGLE tops database. Figure B.8-23 presents this surface. As shown in this figure, over the entire area the Mt. Simon dips approximately 60 feet per mile (approximately 0.65 degrees) to the northwest. Local dip direction is dependent upon formation but appears to be generally north-northwest, consistent in local and regional analyses. It should be noted that this surface does not correspond to the local stratigraphic top presented in Table B.8-2 because it was constructed using regional data that assumed a deeper Mt. Simon top than is currently identified.

B.8.2.2 Local Stratigraphy

Table B.8-2 presents the estimated depths to formation tops. These depths are based on nearby oil and gas wells (with the deepest penetration extending to the Trenton Formation), as well as depths extrapolated from the local structural contour maps described in Section B.8.2, including the Mt. Simon wells at the EGT site (see Figure B.4-1). Table B.8-3 presents the formation thicknesses that are estimated from these data.

Table B.8-2. Estimated Formation Tops at the Proposed CFL Well Locations

Formation	Est. Depth to Top, from GL (ft)* IW#1-36N	Est. Depth to Top, from GL (ft)* IW#2-36E
Ground Level (feet ASL)	627	623
Base of Alluvium/Glacial Material	53	30
Lucas Formation (Detroit River Group)	53	30
Sylvania Sandstone	135	115
Bois Blanc	258	233
Bass Island Group	400	375
Salina Group	650	625
Niagara Group	1,122	1,097
Clinton Group	1,346	1,321
Undifferentiated Upper Cincinnatian	1,652	1,627
Utica Shale	2,227**	2,198**
Trenton Formation	2,357	2,323
Black River Formation	2,765	2,740
Glenwood	3,171	3,141
Trempealeau Formation	3,181	3,151
Franconia/Dresbach Formation	3,281	3,251
Eau Claire Formation	3,366	3,336
Mt. Simon Sandstone	3,527	3,502
Precambrian Granite Wash	3,807	3,782
Precambrian basement	3,827	3,802

*Estimated depths at proposed well locations. All depths shall be determined and finalized during well installation.

** Utica top based on regional map information. Note that often the top is picked higher up the column into the Upper Cincinnatian, resulting in a thicker Utica shale unit.

Table B.8-3. Estimated Formation Thickness at the Proposed CFL Well Locations

Formation	Est. Thickness (ft)* at IW#1-36N	Est. Thickness (ft)* at IW#2-36E
Alluvium/Glacial Drift	53	30
Lucas Formation (Detroit River Group)	82	85
Sylvania Sandstone	123	123
Bois Blanc	142	142
Bass Island Group	250	250
Salina Group	472	472
Niagara Group to Upper Cincinnatian	530	530
Undifferentiated Upper Cincinnatian	575	575
Utica Shale	125	125
Trenton Formation	413	413
Black River Formation	406	401
Glenwood	10	10
Trempealeau Formation	100	100
Franconia/Dresbach Formation	85	85
Eau Claire Formation	161	166
Mt. Simon Sandstone	280	280
Precambrian Granite Wash	20	20
Precambrian basement	Not applicable	Not applicable

*Estimated thickness, both IW#1 and IW#2 locations. All thicknesses shall be determined and finalized during well installation. Note that formation thicknesses at each site are assumed roughly equivalent at this time, although actual thicknesses may vary.

The top of the Mt. Simon Sandstone is projected to be at approximately 3,527 ft BGL at IW#1-36N and 3,502 ft BGL at IW#2-36E, and is approximately 280-300 feet thick near the CFL site. The proposed Injection Zone consists of the Glenwood, Trempealeau, Franconia/Dresbach, Eau Claire, and Mt. Simon Formations; the overlying Trenton/Black River and Utica Shale compose the Upper Confining Zone. The proposed Injection Interval includes the Franconia/Dresbach through the Mt. Simon.

B.8.2.2.1 Precambrian

The Precambrian Granite Wash was encountered at the EDS/EGT locations located approximately 7 to 11 miles northeast of CFL. This unit is described as quartz, clastics, and mineral fragments that are generally angular to very angular, tabular, and platey. The wash is orange/red with dark green tints, with some recrystalized quartz grains that are lighter/tan or cream in color. Chlorite, mica, black mineral fragments, and plagioclase fragments are present; it is described as having “no porosity”. Due to limited well control in the area, a local structure contour map of the top of the Precambrian basement was not constructed, but appears to occur at approximately 3,802 to 3,827 feet BGL near the site at the two proposed well locations (see Table B.8-2).

B.8.2.2.2 Cambrian (Injection Zone)

Mt. Simon (Injection Interval)

The Mt. Simon is a thick and ubiquitous sandstone sequence that is present above the Precambrian in the Site area. Figure B.8-23 is a structure contour map constructed at the top of the Mt. Simon, and Figure B.8-24 is a local isopach map of the Mt. Simon. These maps show that the Mt. Simon is present throughout the area, and is approximately 280 feet thick in the Site area, though inclusion of the granite wash in this interval may increase thickness by about 20 feet. Observed thicknesses at the EDS/EGT wells is approximately 335 feet. Farther to the west at the Pfizer wells, the Mt. Simon is approximately 650 feet thick.

Cores were taken from the Mt. Simon in the EDS/EGT Well #2-12; core data are summarized in Table B.8-4. Note that the upper Mt. Simon sample was located at the Eau Claire contact.

Table B.8-4. Environmental Disposal Systems, Inc., EDS #2-12, Mt. Simon Core Data (12-12-01)

Depth	Porosity (Helium)	Permeability (K_{air})
Top Depth: 4,127.0 ft. Bottom Depth: 4,148.0 ft. Number of Samples: 21	Arithmetic Average 4.8% Minimum 2.8% Maximum 8.6% Median 4.1%	Arithmetic Average 1.10 md Minimum 0.01 md Maximum 8.03 md Median 0.09 md
Top Depth: 4,245.0 ft. Bottom Depth: 4,258.0 ft Number of Samples: 13	Arithmetic Average 10.4% Minimum 5.9% Maximum 13.7% Median 10.8%	Arithmetic Average 25.3 md Minimum 0.01 md Maximum 208.0 md Median 7.99 md

Core data indicate that the porosity in deeper Mt. Simon core ranges from 5.9 - 13.7%, while horizontal permeability to air ranges from 0.01 md to 208 md. Core is described as a grey to tan sandstone, fine to very fine grained, poorly cemented with dolomite. Core collected near or at the top of the Mt. Simon exhibit porosity ranging from 2.8 to 8.6%, with permeability ranging from 0.01 md to 8.03 md.

Historical reservoir testing and pressure falloff tests have been conducted at the EDS well #1-12, which are summarized in Table 8.4a (Petrotek, 2018). Permeability values from testing indicate a range of values from approximately 71 to 165 millidarcies (md). In addition, a pressure interference test was conducted between EDS #1-12 and #2-12 in June 2002 (Subsurface, 2002). This testing indicated that the reservoir encompasses two distinguishable hydraulic units, one with a permeability of 400 md and a thickness of 33 feet, and the other with a permeability of 63.4 md and a thickness of 190 feet. Based on this interference test, the total average permeability of these intervals is equal to approximately 113 md over a total thickness of 223 feet. Based on the results of these tests, an assumed permeability of 110 md over a thickness of 210 feet is conservatively assumed to represent the injection interval at the CFL wells.

Table 8.4a. Historical Reservoir Testing, EGT Well #1-12

Well ID	Date	Gauge Depth (feet KB)	kh (md-ft)	k (md)	Skin	P* (psig)	Final Shut-in Pressure (psig) @ Gauge Depth
1-12	2015	3,950	20,216	152	84	1,773	1,774.9
1-12	2016	3,950	22,225	165	41	1,755	1,761.3
1-12	2017	3,950	14,160	106	44	1,792	1,794.0
1-12	2018	3,950	9,488	71	37	1,804	1,796.7

Fluid samples from the Mt. Simon Sandstone were obtained by EDS via DST during drilling and completion of the EDS #2-12 well. The fluid sample TDS value was approximately 270,000 mg/L. Table B.8-5, below, presents water quality data obtained from the EDS #2-12 well.

Table B.8-5. Environmental Disposal Systems, Inc., Mt. Simon Formation Brine Fluid Analysis, EDS #2-12 (12-12-01)

Analysis	Concentration	Units	Data Completed
Conductivity SM 2510-B	16,200	uS/cm	12/17/01
Magnesium EPA 242.1 FLAA	2,900	mg/L	12/20/01
Potassium EPA 258.1 FLAA	1,910	mg/L	12/19/01
Sodium EPA 273.1 FLAA	39,400	mg/L	12/20/01
Alkalinity (Bicarbonate) SM2320-B	13	mg/L	12/20/01
Alkalinity (Carbonate) SM2320-B	ND	mg/L	12/20/01
Chloride EPA 325.2	141,100	mg/L	12/31/01
pH EPA 150.1	5.5	s.u.	12/19/01
Residue, Filterable (TDS)/SM2540C	270,100	mg/L	12/19/01
Sulfate EPA 375.4	146	mg/L	01/03/02
Sulfide SW846-9030A	N/D	mg/L	01/03/02
Temperature SM2550B	20.6	Degrees C	--

Recent Reservoir Characteristic Analysis to Support CO2 Sequestration

The Mt. Simon has recently been studied as a possible candidate formation for CO_2 injection and results of these analyses also provide information pertinent to fluid injection. Barnes et al. (2009) evaluated the sedimentary facies, lithology, and petrophysics of the Mt. Simon in western Michigan to further understand porosity and permeability development. These authors recognized that the Mt. Simon can be subdivided into three general units: a basal pink-red hematite-stained arkosic unit, central medium-coarse grained quartz sandstone with minor shale/glauconite, and upper transitional calcareous, argillaceous sandstone with fine-grained arkose interbeds that occurs conformably below the Eau Claire. However, extension of these lithofacies to the far east is difficult; see regional cross sections B.8-4 and B.8-5 which demonstrate that while the Mt. Simon is ubiquitous throughout Michigan, thickness and depositional characteristics are highly variable between western and eastern Michigan.

Eau Claire Formation (Injection Interval)

Regionally, the Eau Claire is highly variable from a compositional standpoint, consisting of fine grained sandstone with dolomitic cement in its lower half and siltstones, shales, and sandstone in the upper half. The entire thickness is glauconitic. The Eau Claire thickens to over 800 feet toward the center of the Michigan Basin (Figure B.8-9), and is approximately 160-190 or more feet thick in the CFL area. Note that the Eau Claire-Mt. Simon contact is highly gradational, therefore estimate of both Mt. Simon and Eau Claire thickness are estimates and vary depending on where that contact is selected.

The Eau Claire was cored in the EDS #1-12 and EDS #2-12 wells. Summary results of core analyses for the Eau Claire are presented in Tables B.8-6a and B.8-6b. Note that well EDS #1-12 is a directional well, therefore the core depths are not consistent with corrected formation tops at EDS #2-12. These data show that the sampled portion of the upper Eau Claire in EDS #1-12 exhibits a porosity ranging from 1.2-3.9%, with an average permeability K_{air} of 0.10 md. The lower portion of the Eau Claire at EDS #1-12 exhibits a porosity ranging from 5.4% to 20.7%, with an average permeability of 13.3 md. The upper Eau Claire core is described as a dolomite with laminar bedding and slight anhydrite; the lower Eau Claire core is described as a fine to medium grained sandstone.

Table B.8-6a. Environmental Disposal Systems, Inc., EDS #1-12, Eau Claire Core Data (1-28-02)

Depth	Porosity (Helium)	Permeability (K_{air})
Upper Eau Claire		
Top Depth: 3,060.0 ft. Bottom Depth: 3,090.7 ft. Number of Samples: 31	Arithmetic Average 2.1% Minimum 1.2% Maximum 3.9% Median 2.1%	Arithmetic Average 0.10 md Minimum 0.01 md Maximum 0.66 md Median 0.04 md
Lower Eau Claire		
Top Depth: 4,155.0 ft. Bottom Depth: 4,187.3 ft Number of Samples: 32	Arithmetic Average 10.8% Minimum 5.4% Maximum 20.7% Median 10.1%	Arithmetic Average 13.3 md Minimum 0.06 md Maximum 73.0 md Median 5.91 md

Table B.8-6b. Environmental Disposal Systems, Inc., EDS #2-12, Lower Eau Claire Core Data (12-12-01)

Depth	Porosity (Helium)	Permeability (K_{air})
Top Depth: 4,127.0 ft. Bottom Depth: 4,148.0 ft. Number of Samples: 21	Arithmetic Average 4.8% Minimum 2.8% Maximum 8.6% Median 4.1%	Arithmetic Average 1.10 md Minimum 0.01 md Maximum 8.03 md Median 0.09 md

As shown on Figure B.8-25, regional data suggest the Eau Claire is approximately at least 180 feet thick in the Site area.

Dresbach (Galesville) and Franconia (Injection Interval)

The Dresbach is described as a sandstone that is clear to frosted; it is very fine to coarse grained with moderate to well-sorted subangular to rounded grains and trace glauconite. The Dresbach was not cored at either EDS well. Regional maps indicate this unit could be 50 feet thick, but local well data at the EDS locations combines the Franconia/Dresbach as a single interval that is approximately 50 feet thick in total. At EDS 2-12, the Franconia is described as a grey sandstone that is very fine grained with grey dolomite; it is also glauconitic and dolomitic at the base.

B.8.2.2.3 Ordovician (Injection Zone and Confining Zone)

In contrast to the deeper Cambrian units, units within the Ordovician are composed predominantly of carbonates, indicative of changes in the regional depositional systems. Ordovician units present at the Site are described below.

Trempealeau Formation (Injection Zone)

In western portion of Michigan, the Trempealeau is described as dolomite that is sandy at the base, with decreasing sand percentage up-section. The dolomites are light tan to tan and grey in color, with red/pink coloration and varying intercrystalline porosity. The units are variably described as fine to medium grained (sucrose to micritic), and may contain shale that is present in traces. Glauconite is also present. Figure B.8-12 is an isopach map of the Trempealeau, which shows that the interval to be 50-100 feet thick in the CFL area, which was verified by local data at the EDS wells, where the Trempealeau is approximately 120 feet thick.

The Prairie du Chien Group occurs above the Trempealeau, and is early Ordovician in age. It is present elsewhere in the state, but is absent below the CFL site.

Glenwood Shale-St. Peter Sandstone Interval (Injection Zone)

Regionally, the Glenwood-St. Peter Sandstone interval occurs above the Prairie du Chien interval and is up to 100 ft thick in western portions of the state. However, below the CFL, the unit is likely a very thin dolomite (less than 10 feet).

Black River Formation - Trenton Formation (Confining Zone)

The Black River Formation is ubiquitous in the Site area. It is composed of limestone that is described as light tan to grey and buff in color, and finely crystalline to chalky to micritic, with a few imbedded dolomite rhombs. Occasional shale intervals are described (although not present throughout). The Black River Group may also contain occasional sandstone intervals (described as white, quartizitic, and fine grained), as well as dolomite zones with traces of chert. The basal limestone is described as “pure” with little insoluble residue. In the CFL area, the Black River is described in the EDS wells as a thick, occasionally argillaceous dolomite that is typically dense. The Black River is approximately 400 feet thick at the EDS wells, and is expected to exhibit comparable thickness below CFL.

The overlying Trenton Formation is composed almost entirely of dolomites with some limestone intervals. Dolomite may be finely crystalline with scattered vugs and occasional carbonaceous partings. Dolomites may be brown to white, with limestones being grey to tank in color. In total, the Trenton-Black River is expected to be about 800 feet thick at CFL (Figure B.8-26).

Well log data at the EDS #1-20 well indicate that the average neutron porosity of the Trenton-Black River interval is generally 1-3%, noting that there may be more porous intervals. The Black River at EDS #1-20 exhibits a log porosity of approximately 2% throughout the entire interval, which is 454 feet thick (3,692-3,238 ft RKB). Regionally and where the Trenton-Black River is unfractured, porosity ranges from 2-5% and permeability of generally low (less than 10 mD, but lower than 0.01 mD) (Grammer, 2006).

It should be noted that the Trenton was pursued as a hydrocarbon producing zone to the north of the CFL site. Southeastern Michigan has several Trenton hydrocarbon producing fields, notably associated with structural features and hydrothermal dolomite development. As shown in Figure B.8-27, there are no significant structural features at the top of the Trenton in the CFL region, thus reducing the likelihood that this formation exhibits satisfactory reservoir characteristics and thus would not be pursued for hydrocarbon production. In fact, the single producing well in the nearby Sumpter field, the DeRoy 1 (T4S R8E Section 22), which was plugged and abandoned in 1947.

The Black River Formation is estimated to be approximately 400 or more feet thick at the Site, and the Trenton Formation is estimated to be approximately 400 feet. The thickness estimates are based on data obtained at the EDS well locations, as well as general information from nearby Trenton wells. However, these wells did not fully penetrate the Trenton Formation and typically total depths (TD) are 100-150 feet below the formation top. None of the wells within the 2-mile Area of Review are documented to have penetrated to the Black River, indicating that the lower 300-400 feet of the confining zone has not be penetrated by oil and gas wells within two miles of the proposed well locations. See Attachment B.4 for additional information.

Utica Shale (Confining Zone)

The Utica Shale is present throughout the Site area. The Utica Shale is described as a medium grey to grey-green shale with occasional brown shale partings; some well log cutting descriptions elsewhere in the state describe the shale as being blue-grey, muddy, and “gummy”. It is worth noting that the Utica Shale is in the lower Cincinnatian; locally, the upper Cincinnatian includes up to 235 feet or more of shales, that also offer upper confinement. Core was collected from this upper Cincinnatian Shale at the EDS No 2-12 well; Table B.8-7 presents this core information. As shown in Table B.8-7, porosity of the upper Cincinnatian ranges from 1.1-3.5%, and permeability varies from 0.01 md to 10.6 md.

Table B.8-7. Environmental Disposal Systems, Inc., EDS #2-12, Upper Cincinnatian Core Data (12-12-01)

Depth	Porosity (Helium)	Permeability (K_{air})
Top Depth: 2,505.0 ft. Bottom Depth: 2,535.0 ft. Number of Samples: 30	Arithmetic Average 2.2% Minimum 1.1% Maximum 3.5% Median 2.2%	Arithmetic Average 2.18 md Minimum 0.01 md Maximum 10.6 md Median 1.41 md

Sattler and Barnes (2018) noted that "The Utica Shale and Maquoketa Shale are considered to be the primary confining layers for Cambrian-Ordovician CO2 sequestration in the Midwest in the Michigan and Illinois Basins, respectively…" and "The Utica Shale is a notable confining zone in the region because of its widespread lateral continuity, dense mudrock lithology, and thickness in excess of 30 m." Sattler (2015) evaluated Utica porosity and permeability measurement data obtained from core obtained from wells in nearby Lenawee and Jackson county; these are the closest wells in Sattler's 2015 report to the proposed CFL well locations.

Well	County	Utica Depth	Utica Porosity	Utica Permeability (orientation no defined; likely horizontal	Comment
Thompson 1-30	Lenawee	2,277 ft BGL	0.77%	0.003 mD	Similar depth to top of Utica at CFL
Arco-Conlkin 1-31	Jackson	3,696 ft BGL	2.78%	14.71 mD	Slightly deeper to top of Utica than at CFL

The Utica-Trenton contact is abrupt, with the Utica deposited in an open marine environment (Sattler, 2015). Michigan core verifies the marine depositional setting, described as a sometimes fossiliferous grey to black mudstone with pyrite and calcareous lenses. Some vertical fractures were observed in core that were typically cemented with calcite or gypsum/anhydrite but fracturing was not described as laterally or vertically pervasive (Stattler, 2015). The Utica Shale gamma ray log response is typical of dense mudrock lithologies, and the response is generally consistent throughout the Michigan Basin although thickness may vary (Sattler, 2015).

The Utica shale is approximately 125-140 feet thick or more in the CFL area. Figure B.8-28 is an isopach of the Utica Shale, and Figure B.8-29 is a structure contour map constructed at the top of this shale.

B.8.2.2.4 Silurian, Devonian and Mississippian Units

Devonian and Mississippian-aged units are discussed in Sections B.8.1.3.4 and B.8.1.3.5 of this document. The units include the Undifferentiated Cincinnatian, Manitoulin Dolomite, Cabot Head Shale, Clinton Group, Niagara Group, Salina Group, Bass Islands Group, and Detroit River Group, with units above these absent by erosion at the CFL area. In total, this interval is estimated to be over 2,000 feet thick at the Site.

B.8.2.2.5 Alluvium and Glacial Material

Unconsolidated material of various origins and characteristics are present in the Site area. Figure B.8-17 shows the glacial clay/drift thickness to be approximately 50 feet, while Figure B.7-18 shows the total thicknesses of the overlying alluvium and till to not exceed 75 feet in the site area. Local data suggest that the total thickness of glacial clay will not exceed 53 feet at the selected CFL well locations (City Management Corporation, 1991).

B.8.2.3 Local Seismic Activity

The Site occurs in a region where only minor occurrences of seismic activity have been detected (USGS, 2017). Figure B.8-19 shows that the Site area is located in an area with low peak acceleration. No damage from earthquakes is expected. Based on USGS records (https://earthquake.usgs.gov), only four earthquakes have been recorded in Michigan since 1974. Figure B.8-20 presents regional location of earthquakes in southern Michigan, and shows that the CFL site is approximately 75 miles from the closest Michigan earthquake that has occurred in the past 100 years. Table B.8-8 presents information about earthquakes presented in Figure B.8-20, noting that the closest earthquake to CFL was in Ontario over 15 miles away.

Induced seismicity related to human activity is a concern in localized areas elsewhere in the United States, in places such as Oklahoma and Kansas. The USGS recently published a document identifying the likely location of induced seismic events (Figure B.8-30). As shown in this figure, no areas in Michigan are identified as an area for potential induced seismic activity. Induced seismicity can sometimes be of concern in other areas where significant injection occurs near basement rock. In the case of the Mt. Simon, Class I disposal wells occur within the states of Michigan and Indiana, many of which have been in operation for decades and are completed throughout the Mt. Simon and at or near basement. None of the seismic events in Michigan or Indiana have been associated with Mt. Simon deep well injection activities.

Table B.8-8. Earthquakes > 2.5 Magnitude, Southern Michigan Region, 1919-2019

Year	Month	Day	North Latitude	West Latitude	Magnitude	Location
2018	4	20	42.1181	-83.015	3.4	2km E of Amherstburg, Canada
2017	5	14	42.136	-82.41	2.6	18km ENE of Leamington, Canada
2016	2	7	41.6503	-82.8969	2.5	15km NNE of Port Clinton, Ohio
2015	6	30	42.1464	-85.0459	3.3	11km NE of Union City, Michigan
2015*	5	2	42.2357	-85.4285	4.2	5km S of Galesburg, Michigan
2015	2	16	45.0744	-83.502	2.5	Michigan
2013	11	11	41.7999	-87.8247	3.2	1km NW of Summit, Illinois
2013	2	17	42.018	-82.224	2.5	southern Ontario, Canada
2012	9	7	41.864	-83.076	2.5	Ohio
2012	1	26	41.576	-85.49	3	Indiana
2011	2	23	42.157	-82.43	3	southern Ontario, Canada
2010	5	17	41.24	-81.51	2.7	Ohio
2010	5	14	41.39	-83.3	2.7	Ohio
2010	3	8	42.163	-83.07	2.5	Michigan
2007	4	12	41.722	-82.924	2.8	Lake Erie, Ohio
1994	9	2	42.798	-84.604	3.5	Michigan
1984	1	14	41.645	-83.427	2.5	Ohio
1980	8	20	41.941	-83.01	3.2	Ohio
1976	2	2	41.96	-82.67	3.4	Ohio
1974	9	29	41.238	-83.361	3	Ohio
1947	8	10	41.928	-85.004	4.6	Indiana

Source: National Earthquake Information Center
*University of Michigan, 2015

B.8.2.4 Karst, Mines, and Other Features

Form EQ 7200-14 required the identification of faults, structural features, karst, mines and lost circulation zones within the Area of Review that can influence fluid migration, well competency, or induced seismicity. Faults and structural features were addressed in Sections B.8.1.2 and B.8.2.1.

The presence of karst is possible where carbonate beds are near surface with the potential for influx of water that would facilitate dissolution. Sinkholes have been identified in Monroe county where carbonate units occur near ground level, and both Wayne and Monroe County have been identified as areas where sinkholes are infrequent or likely infrequent (Michigan State University Extension, 2008). The possibility of carbonate dissolution features near surface, and particularly within the

Lucas that subcrops below the CFL, will be assessed during well installation.

Bedded salt is present in the shallow subsurface north of CFL, particularly near Detroit. Salt mine location is predicated by the occurrence of bedded salt near ground level, with the Salina Group the primary source of bedded salt. However, in the Carleton area, the Salina Group contains very little salt, and there is no information to indicate that salt mining (either dry or solution) occurs or has occurred within the AOR (http://geo.msu.edu/extra/geogmich/saltminingM.html). Further, there are no other known resources that are mined within the AOR.

B.8.3 Conclusion

Data presented in this section indicate that the Site satisfies the geologic criteria for siting of Class I waste disposal wells by demonstrating that site stratigraphy, structure, hydrogeology and seismicity of the area meet these standards and criteria. Geologic properties are well defined, and as illustrated by geologic characterization and historic operation of neighboring wells, the Injection Interval has sufficient permeability, porosity, thickness and areal extent to accept injectate and prevent migration of fluids into USDWs. The Injection Zone, Injection Interval, and the Confining Zone are laterally continuous and free of transecting transmissive faults or fractures within the AOR. Further, the Injection Interval is separated from the top of the Confining Zone by sequences of permeable and less permeable strata that prevent vertical fluid movement. The Confining Zone is also separated from the base of the USDW by multiple sequences of permeable and less permeable strata that serve to prevent vertical fluid movement.

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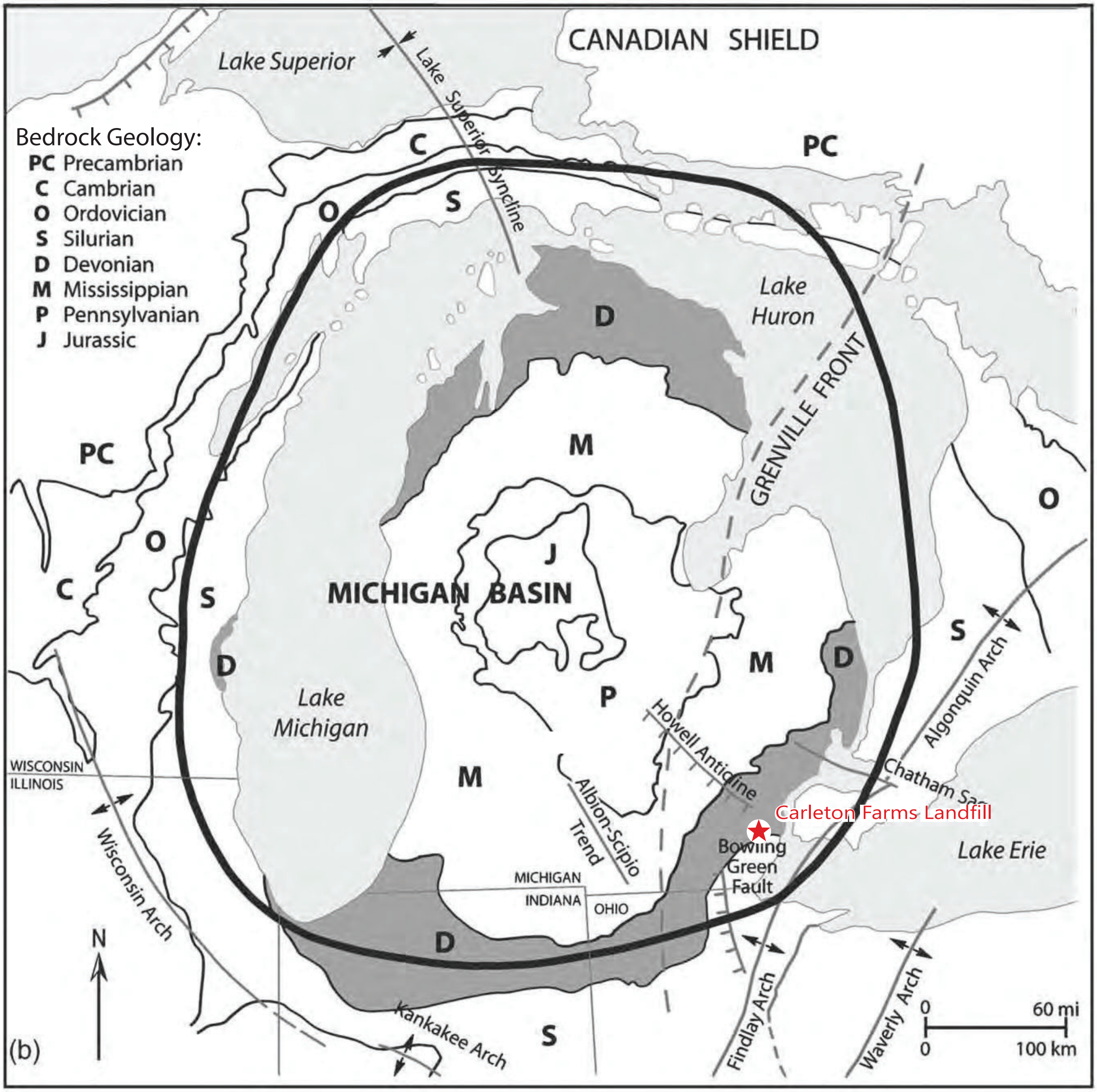

Modified from : Catacosinos et al., 1991

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Figure B.8-1
General Geology and Structural Features of the Michigan Basin
2019 Permit Application

Scale: See Bar Scale	Date: September 2019	
2019_CFL_EGLE_Fig_B.8-01.pdf	By: WEK	Checked: CW

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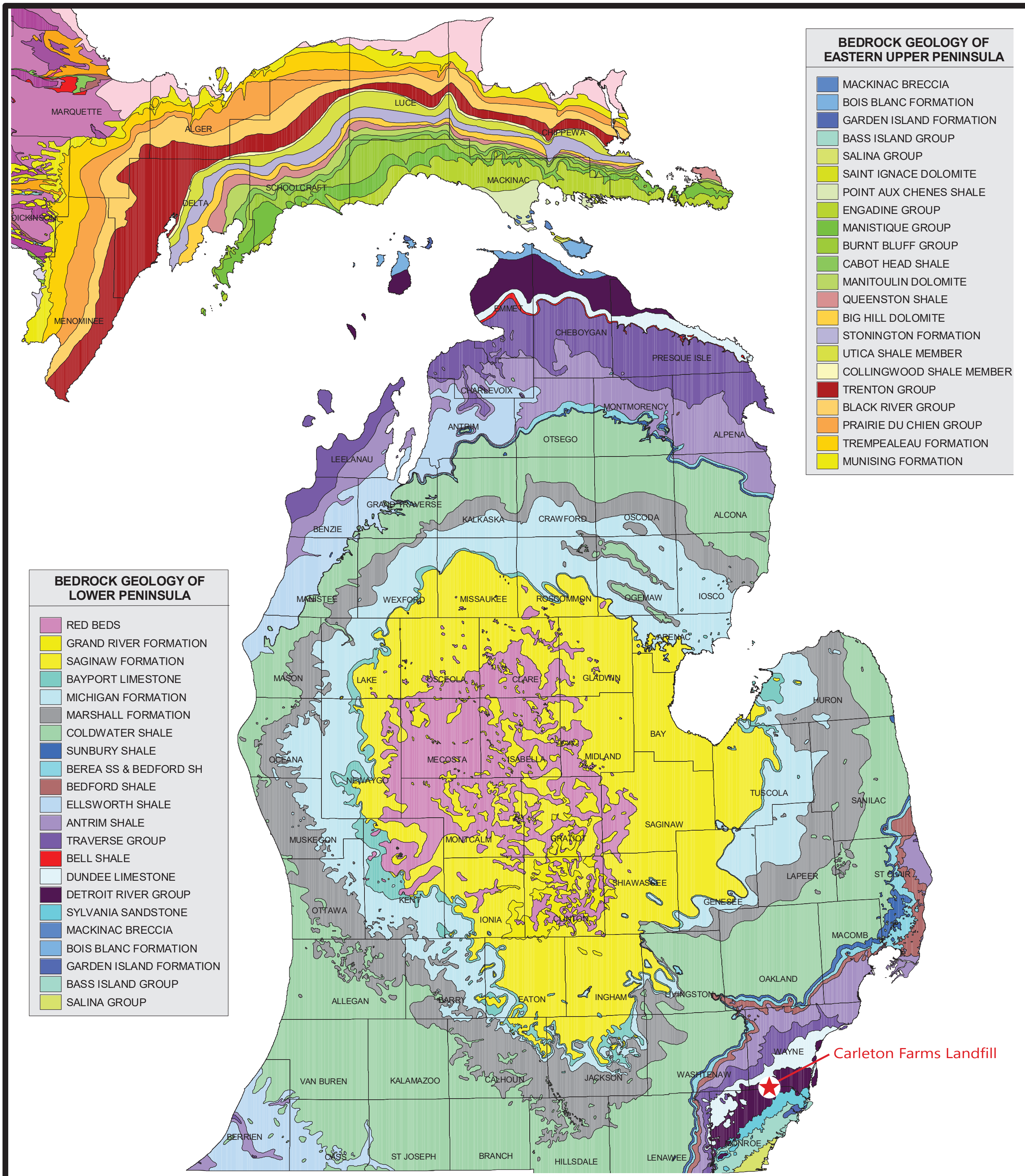

SOURCE

MICHIGAN DEPARTMENT OF NATURAL RESOURCES
LAND AND MINERALS SERVICES DIVISION
RESOURCE MAPPING AND AERIAL PHOTOGRAPHY

Michigan DNR

RMAP

Michigan Resource Information System
Part 609, Resource Inventory, of the Natural Resources and Environmental Protection Act, 1994 PA 451, as amended.

Automated from "Bedrock Geology of Michigan," 1987, 1:500,000 scale, which was compiled from a variety of sources by the Michigan Department of Environmental Quality, Geological Survey Division.

Date: 11/12/99

0 20 40 Miles

REPUBLIC SERVICES

Figure B.8-2
Regional Bedrock Geology of Michigan
2019 Permit Application

Scale: See Bar Scale	Date: September 2019
2019_CFL_EGLE_Fig_B.8-02.pdf	By: WEK / Checked: CW

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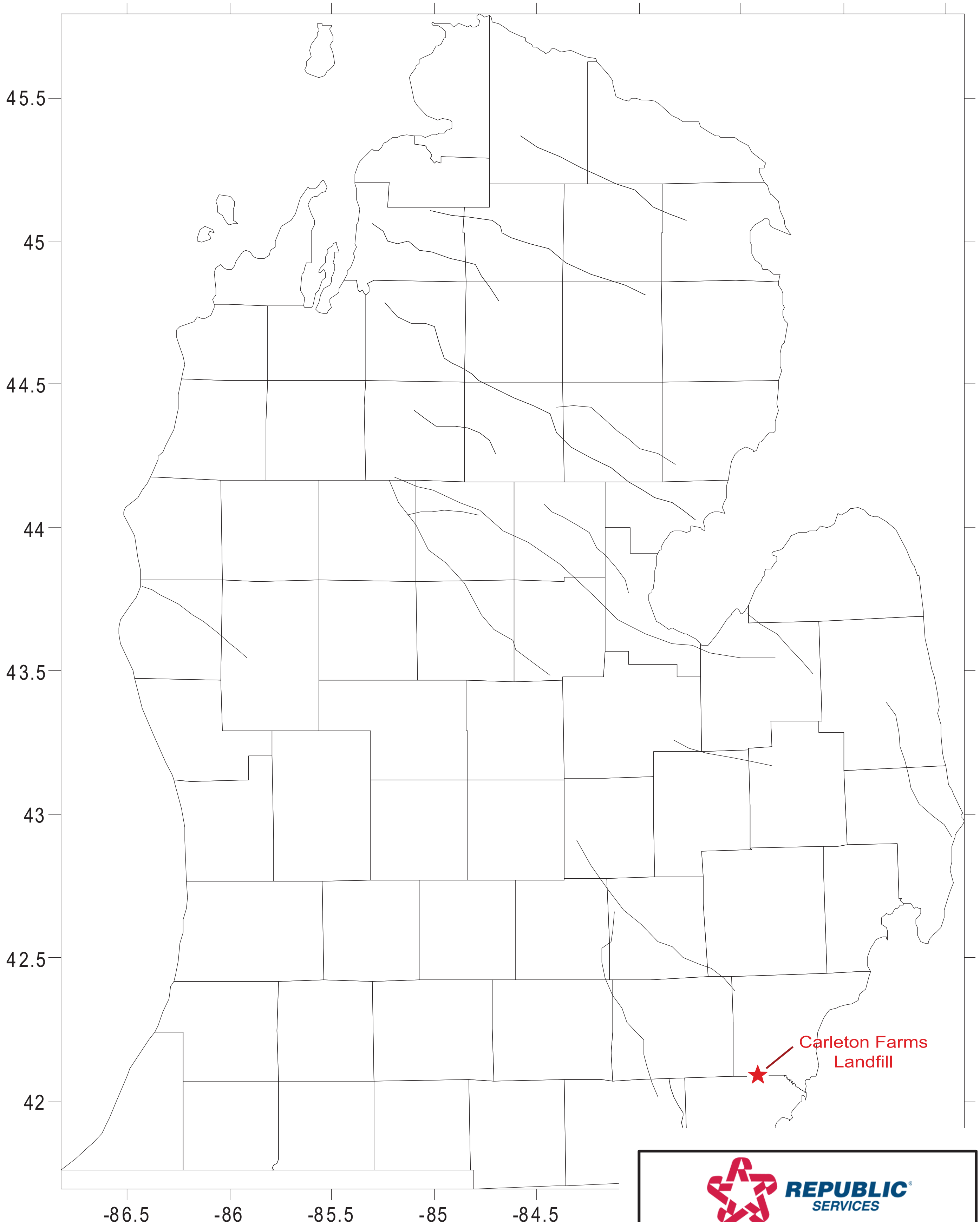

From: Wood and Harrison, 2002

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Figure B.8-3
Dundee Lineaments, Michigan Basin

2019 Permit Application

Scale: NTS	Date: September 2019	
2019_CFL_EGLE_Fig_B.8-03.pdf	By: WEK	Checked: CW

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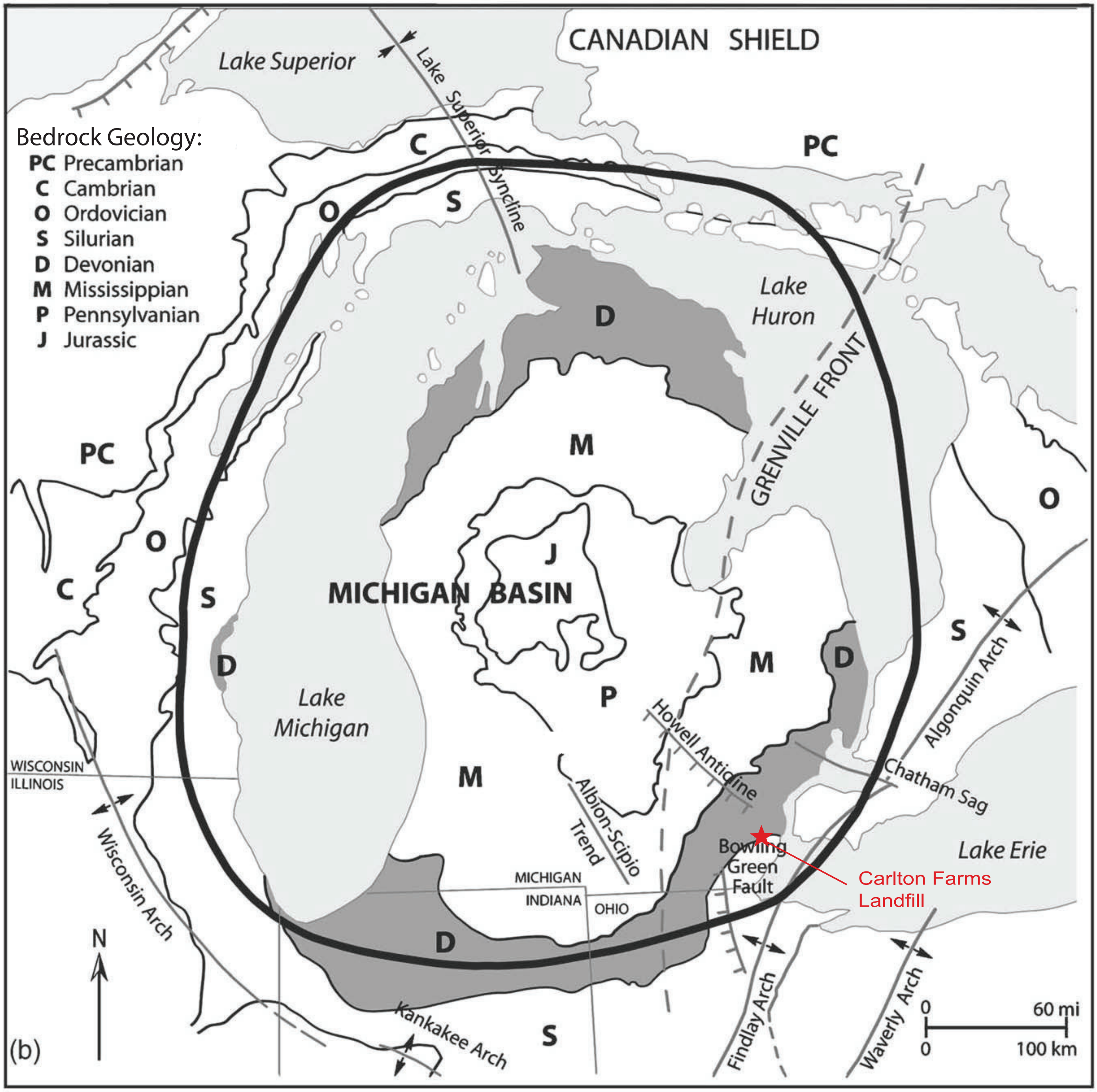

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Figure B.8-3A
General Geology and Structural Features of the Michigan Basin
2019 Permit Application

Scale: See Bar Scale	Date: September 2019	
2019_CFL_EGLE_Fig_B.8-03A.pdf	By: WEK	Checked: CW

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